Automotive IoT 2018

Abstract:

This report provides a view of how connectivity is changing for the automotive market, including a review of DSRC vs Cellular V2X options, the evolution of telematics for several new business models and requirements.   Technical, political, and economic factors are all weighed to predict the most likely outcomes. Infotainment, OTA updates, V2V safety, mapping, insurance, and other applications are translated into requirements for RF modules, with a 10 year forecast broken down by 802.11p/LTE/5G level, MIMO configuration, band coverage, regional usage, and other key factors.

November 2018

MOBILE EXPERTS

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Automotive IoT Devices 2018

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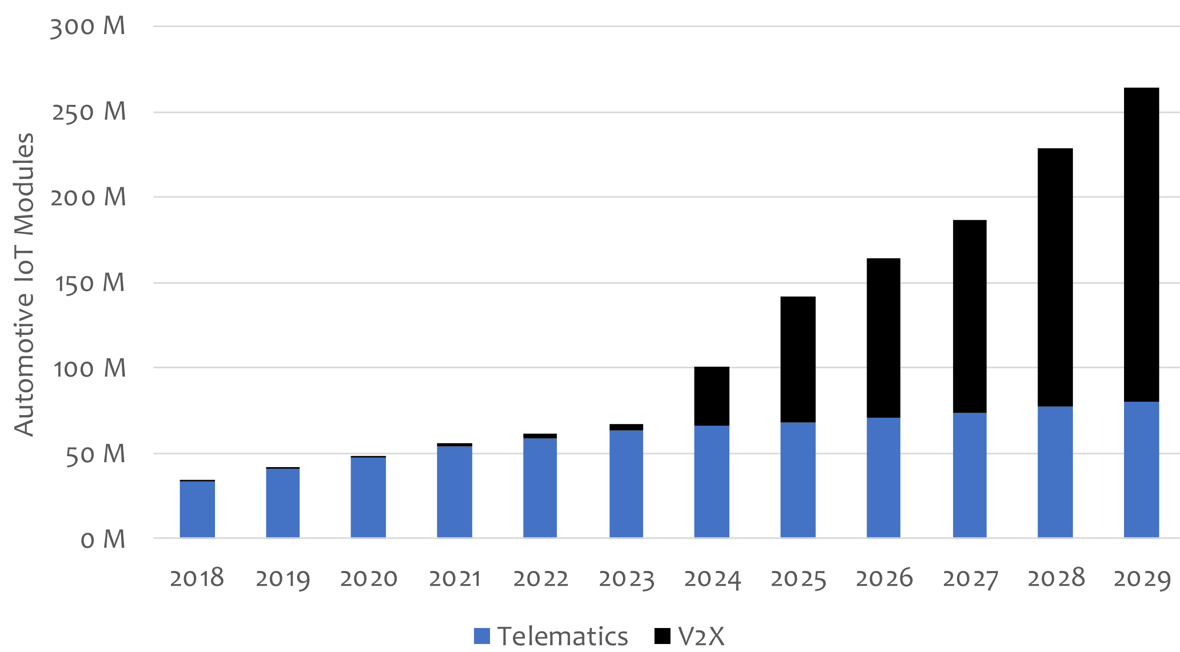
1: *EXECUTIVE SUMMARY*

The automotive market is buzzing with activity surrounding connectivity and dozens of new applications that use wireless technology. Dozens of new use cases are emerging for enterprises (OEMs, insurance companies, dealers, fleets, cities) as well as end users (infotainment, navigation, safety). With dozens of auto OEMs experimenting in different directions, multiple conflicting options are possible.

At the same time, the market is exploring the use of radio technology to improve safety through Vehicle-to-Vehicle (V2V) and Vehicle-to-Other (V2X) modules. The adoption of this feature has started only slowly, but we expect some government actions that will drive the market. In this case, government prodding is necessary because no single manufacturer can effectively implement V2V on its own.



Source: Mobile Experts

Chart 1. Overall Summary for Telematics and V2V Module Shipments

The key findings of this report include the following:

- Cellular modem shipments will increase from about 34 million units in 2018 to about 64 million units in 2024. Modem capability is increasing from Cat 4 to Cat 6 and Cat 9 currently, driven by OTA updates and infotainment applications. Eventually we expect the market to shift to 5G modems, starting in the premium segment….but the connection between autonomous vehicles and 5G is not yet proven.

- In the battle between DSRC and C-V2X for safety and ITS applications, DSRC is the primary choice for the short term, in Japanese and North American markets. Cellular technology is newer but has not been as fully tested. We expect China to skip over DSRC and use Cellular V2X instead, and we have modeled two scenarios for Western countries depending on decisions by the US government. We've modeled a ten-year forecast period for this market because growth will be delayed due to long automotive design cycles.
- Electronic toll collection will continue to be highly regionalized and fragmented for the foreseeable future. Some regions favor RFID, others DSRC, and still others use GNSS-based solutions. One significant change is the range of passive RFID tags has improved in recent years, enabling some toll collection systems to offer low-cost lifetime tags vs. higher cost tags limited by battery life.
- Usage-based insurance is migrating away from dedicated hardware to a smartphone application. Insurance companies are actively looking to reduce hardware populations and minimize all costs associated with monitoring driver behavior and mileage.
- Some of the traditional aftermarket telematics suppliers who provided lot inventory, theft recovery, repossession, and usage-based insurance hardware/connectivity/service products have started to reposition themselves as system integrators and service providers. Through key relationships with OEMs fielding connected cars and key relationships with dealership management systems suppliers, these aftermarket telematics providers are creating value by unifying the interfaces seen by dealerships, car rental agencies, and other owners of large fleets.
- Major markets have mandates in place creating guaranteed markets for telematics. China and India require tracking solutions on trucks, buses, school buses, and taxis. The European Union and Russia require eCall and ERA-GLONASS support on all new vehicles. The United States will require all commercial heavy trucks have electronic logging devices communicating data to the FMCSA soon. Australia is beginning to certify electronic logging devices for heavy trucks as well.
- Pending standards for integrating RFID in tires may create a 1.5 billion unit opportunity per year for tags.

2: INTRODUCTION

In our "Automotive IoT 2018" report we present a forecast of wireless technologies used in the automotive, truck, and bus industries across the globe. Starting with a high-level view of the relationships between transportation, infrastructure, cities, and people, we then focus on the vehicle use cases where wireless technology is currently used or might be used in the future. We review the technical and cost tradeoffs of wireless technologies, and consider whether they are being pulled or pushed to the market. Ultimately our goal is to be as realistic and accurate as possible with our forecasts using these perspectives.

This is an interesting moment in time for the auto/truck/bus industry. Early assembly line innovations and subsequent lean manufacturing optimizations are potentially augmented even further with Industry 4.0 initiatives. Electric vehicles are seeing sales acceleration. Advanced powertrain, safety and autonomy, convenience, and entertainment functions are driving substantial increases in computing power and adoption of wireless technologies. Road infrastructure is evolving as well with systems to improve safety and utilization of existing resources. Various private, public, individual, and shared business models are being explored for vehicles and infrastructure.

A century ago the world saw horses, internal combustion engines, and electricity propelling private and public transport on open roads and fixed track together. Today we continue to see evolution in vehicles, ownership and usage models, and infrastructure. Changes in technology may enable the long-established model of private car ownership and public roads, with migration toward automated cars and expensive roadways that include electronic infrastructure.

Source: Wikimedia Commons

Illustration 1. The last of the horse-drawn carriages.

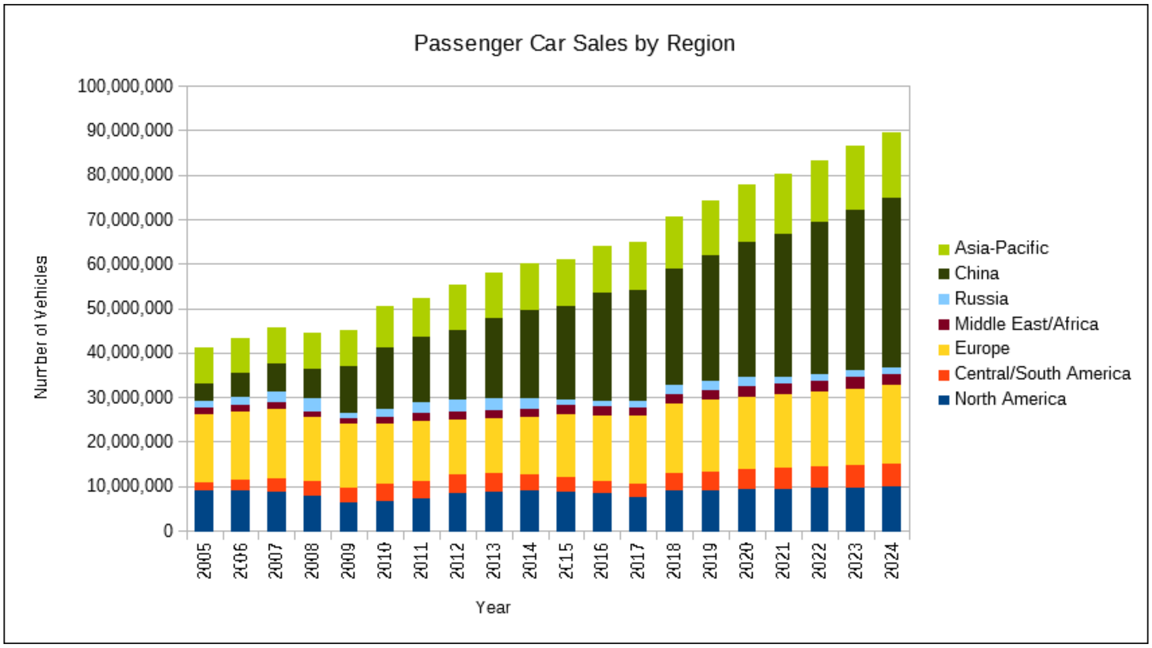
3: MACRO FACTORS

Automobiles, trucks, and buses have radically changed the world; some may say for the better, others may say for the worse. From one perspective we can point to increased personal freedom, national economic growth, and a larger variety of goods and services available in many locales as a byproduct of transportation. From another point of view we can observe the side effects of vehicle proliferation including energy consumption, pollution, traffic congestion, and safety risks. Both perspectives continue to drive improvements in technology, products, and infrastructure. In our study of wireless technologies in vehicles, 46 countries produce and consume roughly 95% of all vehicles on the planet. The following sections bring forward some global trends and observations which may influence the deployment of wireless technology in vehicles.

3.1: Vehicle Adoption as a Product of GDP, Population, Relative Wealth and Country-Specific Factors

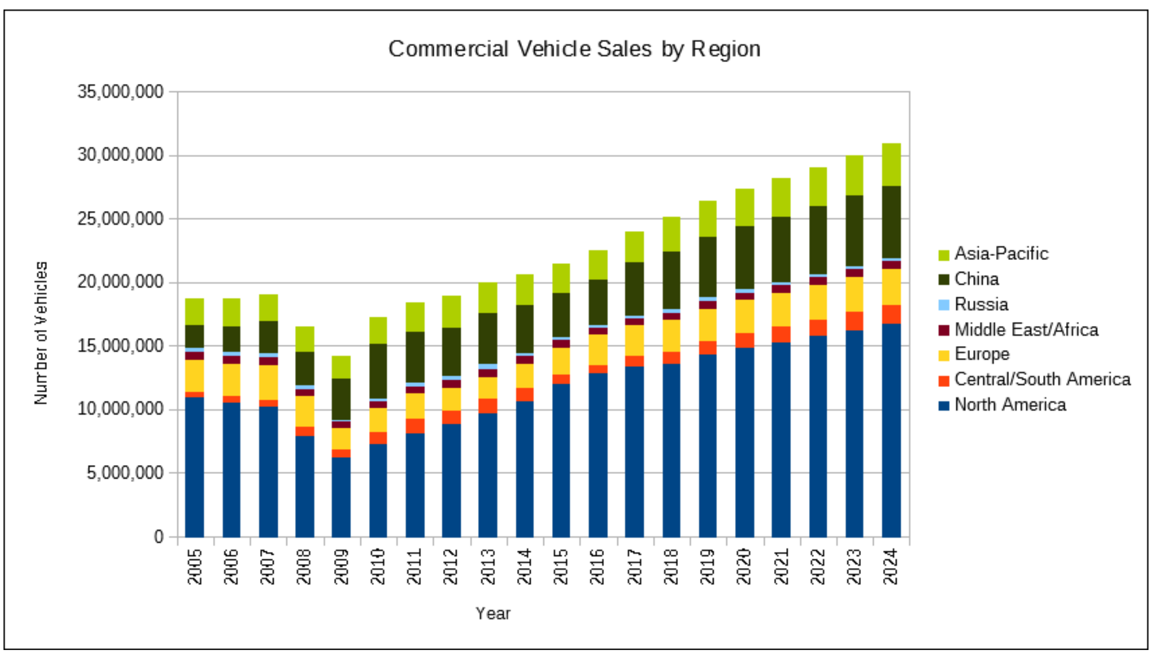
Several studies have considered the quantity of vehicles in a population as a function of per capita GDP (Gross Domestic Product). The result is a type of S-curve where key thresholds define the beginning and saturation points for vehicle adoption. At least one study we reviewed suggested country-specific factors had an influence as well, such as a dependence on foreign oil supplies, maturity of road infrastructure, and availability of public transportation alternatives. Therefore, the rate of vehicle adoption is specific on a country-by-country basis.

Economic forecasts suggest almost all of the 46 countries will experience some degree of real GDP growth over the next 6 years, a little over 3.25% on average annually. The majority of these same countries will experience some population growth, a little under 0.75% on average annually. As a result, GDP on a per capita basis will tend to rise and we expect to see automotive, truck, and bus production and sales increase as well. As shown in Chart1 and Chart 2, vehicle production and sales could increase from 95 million in 2017 to approximately 120 million by 2024 globally.



Sources: Company Disclosures, Mobile Experts

Chart 2. Passenger Car Sales by Region



Sources: Company Disclosures, Mobile Experts

Chart 3. Commercial Vehicle Sales by Region

3.2: Vehicle Lifecycles and Fleet Size

In the 1980s the average automotive design cycle for a major platform took 8.4 years to complete. Now, automotive design cycles have shrunk to 6.7 years, and the amount of content managed during that design cycle has increased substantially. More electronics and software are installed in vehicles today than ever before; some of it in response to safety mandates, some of it offered as differentiated features. In 2016 one major pickup truck model had up to 150 million lines of software embedded in it, about triple the size of a major desktop operating system and 15 times the size of code in a modern military jet fighter.

The age of vehicles on the road varies by country, but in major markets such as the European Union and the United States the average age of passenger cars is close to 11 years and 12 years, respectively. Commercial vehicles tend to have slightly higher average ages, 12 years and 14 years, for these two markets. China's passenger car averages are much lower – 4.5 years – reflecting rapid growth and relative driver experience in that region.

The net effect of increasing vehicle sales and higher average ages is the global registered vehicle fleet is increasing. Total vehicles in use globally including passenger cars, trucks, and buses numbered about 1.3 billion in 2017; some reports suggest the total number of vehicles may rise to 2 billion by 2035. The significance of higher average vehicle ages and larger fleet sizes is the introduction of new technologies into the global fleet takes longer to reach critical levels with each passing year; for example, V2X (Vehicle-to-Everything) depends on network effects to address overarching safety goals.

3.3: Urbanization

All 46 countries we reviewed have increasing rates of urban population with expectations these trends will continue. Half of these countries already have urbanization rates higher than 80%. Not only will there be more people in the world, buying more vehicles, with an increasing number of registrations, but many of these people and their vehicles will reside in urban locations. This will aggravate traffic congestion, pollution, and safety issues in established cities.

Source: Wikimedia Commons

Illustration 2. San Francisco, an Example of Urbanization

3.4: Emissions and Fuel Consumption vs. Fuel Tax Revenue

Many governments introduced emissions and fuel consumption mandates in response to increasing vehicle fleet sizes, the pollution they generate, and the fuel they consume. Depending on the country, these mandates may emphasize greenhouse gas reduction, fuel consumption, or both. In response to these mandates the vehicle manufacturers update their products regularly with newer materials, technologies, and designs.

In some cases the mandates for improved consumption and emissions run counter to the taxes levied on fuel. If the rate of these improvements outpaces the growth in fuel consumption, and if the tax rates remain unchanged on fuel, then the funding for road improvements shrinks especially in light of inflation.

In the United States, for example, the federal fuel tax last changed in 1993 and has stayed constant at 18.4 cents/gallon for gasoline and 24.4 cents/gallon for diesel. Twelve states haven't changed their fuel taxes in over 20 years, either. Yet the inflation from 1993 to 2018 is nearly 75%; state budgets are essentially shrinking for improving and maintaining infrastructure.

This dynamic of emissions and fuel consumption standards combined with fuel tax legislation leaves state departments of transportation looking for creative budget-constrained solutions to traffic congestion and safety issues, as roads have initial costs and ongoing maintenance costs. If more vehicles are sold with hybrid powertrains or pure electric powertrains, then the fuel tax situation could become even more difficult. Governments are hoping to "buy some time" using technology to improve road efficiency and safety, but eventually more taxation and tolling may be needed to maintain infrastructure and shape consumer behavior.

3.5: Traffic Congestion and Safety

Multiple studies on traffic congestion all say the same thing: It's getting worse. Commuters and freight companies in major cities around the world lose time in slow or stopped traffic each day. Older cities are particularly problematic as existing roads may not have the capacity to handle traffic during peak hours, and there is no space available for expansion. Depending on what value is placed on time, the direct and indirect costs of traffic congestion may approach $300 billion a year in the USA currently.

These problems extend to the rest of the world as well. Los Angeles and Moscow share the honor of having some of the worst traffic congestion in the world. Though statistics on Asian countries are more difficult to find, China made international news a few years ago with a traffic jam 100 km long lasting 10 days.

Source: Wikimedia Commons

Illustration 3. Traffic Congestion in Moscow.

Global safety statistics suggest there are about 1.3 million deaths related to car crashes each year currently, and another 20-50 million people injured or disabled. Statistics for the USA indicate nearly 40% of all car crashes occur at intersections, with rear-end collisions contributing as much if not more to the overall crash rate.

Individual departments of transportation are motivated to address traffic congestion and vehicle crash issues, but they are facing a difficult challenge. Finding space to create capacity near older cities is nearly impossible. Road infrastructure upgrades are expensive. Budgets funded through fuel taxes haven't changed in years, and the real purchasing power of those budgets is shrinking. P3 partnerships, toll roads, and intelligent transportation systems are all options for dealing with these issues.

3.6: Safety Mandates

While transportation departments around the world attempt to address efficiency and safety goals from an infrastructure perspective, other governmental agencies focus on the vehicles themselves. NCAPs (New Car Assessment Programs) exist in most major economic regions. These agencies execute crash performance and crash avoidance testing, and provide safety ratings for vehicles available in the market. Many of these NCAP programs have roadmaps of criteria. For example, the European NCAP has a roadmap of safety features through 2025 including automatic electronic braking and V2X technology.

Sometimes specific criteria are simply used for ratings; other times they become mandates. Seat belts, air bags, backup cameras, anti-lock brakes, and vehicle stability controls are some of the mandated features in certain parts of the world. In general, the regions with mature economies are most likely to have the largest number of standard safety features; developing economies are far less likely to mandate these features.

Source: NHTSA

Illustration 4. Crash Performance Testing.

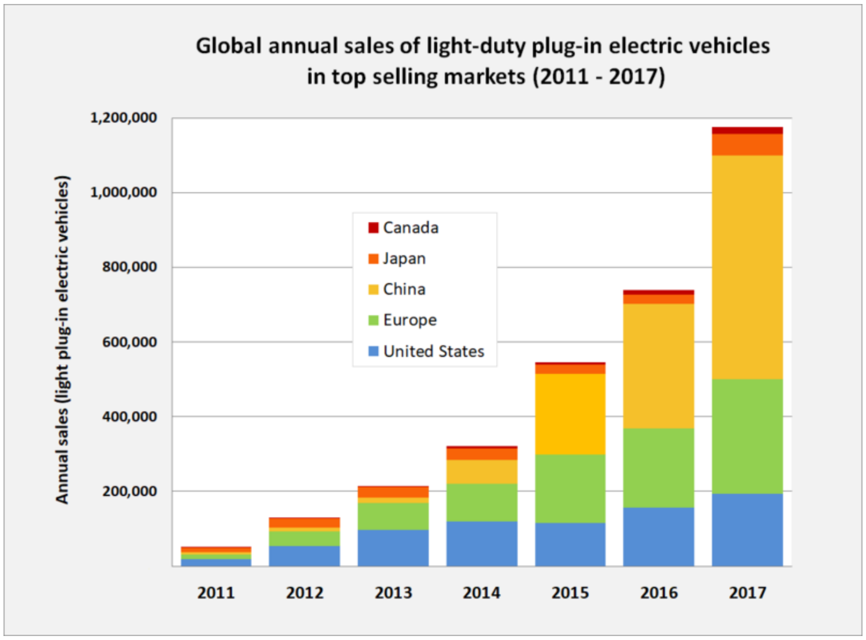
3.7: Vehicle Technology Shifts

Three trends in vehicle technology include electrification, higher levels of ADAS (Advanced Driver Assistance Systems), and more wireless connectivity. In our view these trends operate independently – rates of adoption are not linked with each other.

Electrification refers to the replacement of internal combustion powertrains with batteries and electric motor systems. Instead of a fuel tank, arrays of cells in series/parallel combinations store electrical energy via a battery management system. The energy is delivered from the batteries via motor controllers to one or more electric motors for propelling the vehicle, and these same motors can act as generators to recoup most of the kinetic energy of the vehicle when braking.

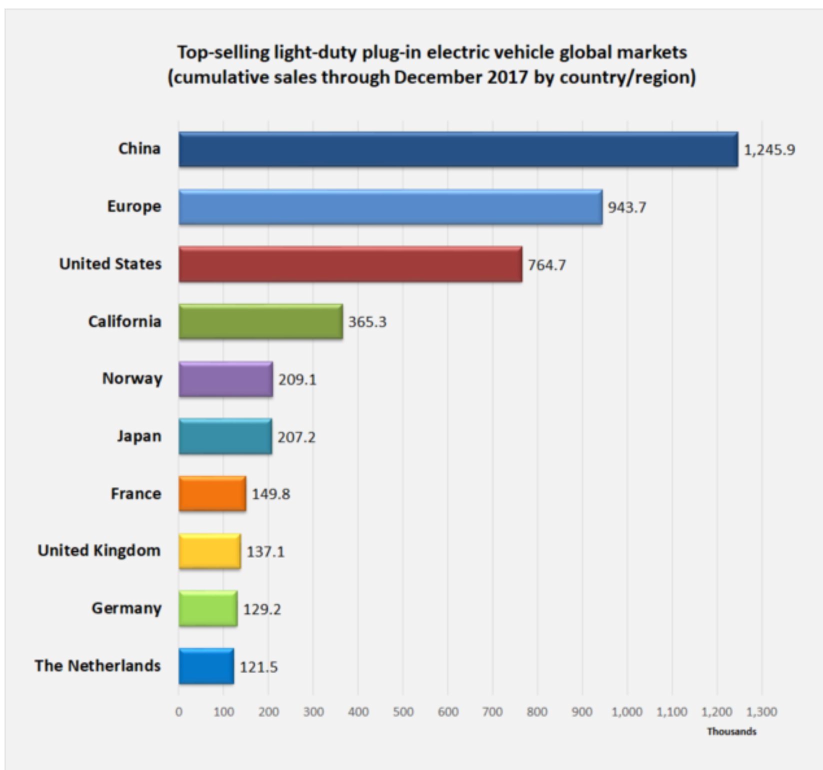
As of late last year, over 3 million EVs (Electric Vehicles) are registered globally. China is the largest market for them with over 1.2 million sold. Europe is the next largest market with about 944 thousand sold. The USA is next with 765 thousand sold. While EVs are still a minor percentage of the total registered vehicle population (about 0.25%), the sales trend is still accelerating. The single most expensive component in an EV, the battery, is expected to drop in cost by 50% over the next 5 years.

In a sense what we're witnessing is a repeat of the situation 100 years ago when the Model T was produced; it had a limited range of a couple hundred miles, cost significantly more when first introduced, and didn't have an extensive network of refueling stations. Improvements in manufacturing efficiency lowered costs to point where an average person could afford the product. Increasing numbers of vehicles represented an opportunity to establish large fuel delivery networks. Design improvements and cost improvements in batteries and motors may very well lead to history repeating itself.



Source: Mariordo

Chart 4. Annual Sales of Plug-In Electric Vehicles.

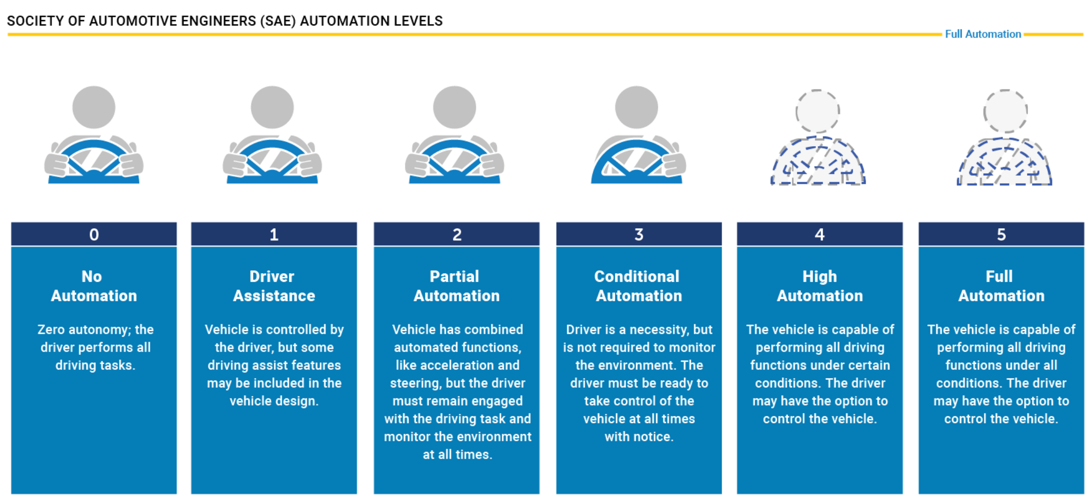


Source: Mariordo

Chart 5. Cumulative Sales of Plug-In Electric Vehicles.

ADAS introduces increasing levels of safety and autonomy in vehicles. Within the automotive industry these systems are classified by the degree of help they provide the driver.

- Level 1: Older, more established technologies such as anti-lock brakes, traction control, and vehicle stability control.
- Level 2: Adaptive cruise control, lane keeping, and self-parking.
- Level 3: Possibly cruise control coupled with self-steering in highway conditions; it's nearly a self-driving car except the driver must be ready to assume control again at a moment's notice.
- Level 4: Near autonomy; the human driver still has the option to take control of the vehicle. While the lowest levels of ADAS are based on simple sensors and classic control schemes, as higher levels of autonomy are introduced the sensor complexity and computational load increase exponentially.
- Level 5: Reserved for fully autonomous vehicles where the vehicle owner is no longer a driver at all – he is relegated to the role of passenger and simply tells the vehicle where he wishes to go. This full autonomy depends on large data sets and complex weighted classification algorithms; this would certainly be a reason for connectivity just to receive regular firmware and data updates as fleets of vehicles "learn" and adapt to new conditions on the road.



Source: NHTSA

Illustration 5. SAE Automation Levels.

Finally, wireless technology adoption in new vehicles is higher than it has ever been. Bluetooth for hands-free calling, messaging, and streaming music is nearly ubiquitous. Safety mandates and evolving business models are driving cellular adoption to new highs. Wi-Fi (Wireless Fidelity), coupled with cellular modems, provides mobile hotspot capabilities to passengers. Wi-Fi also has the potential to offload some telematics data transmissions and OTA (Over The Air) firmware updates from the cellular network. GNSS (Global Navigation Satellite System) time and location data are used extensively in infotainment and safety systems. Electronic toll collection systems and parking management systems are leveraging RFID (Radiofrequency Identification) and DSRC (Dedicated Short Range Communications). Next-generation safety systems are considering DSRC and C-V2X (Cellular Vehicle-to-Everything) technologies as well.

3.8: Consumer Technology Adoption

Roughly two-thirds of the world's population own smart phones, and that statistic continues to climb. Smart phones are highly interactive and provide many of the capabilities of a general-purpose computer with Internet access. People want to use their phones while on the move, and this has led all 46 countries in our study to mandate no handheld use of a phone while operating a motor vehicle. As a result, even some of the least expensive cars available include Bluetooth to support hands-free calling, messaging, and music playback through the vehicle's sound system. Japan, and a few states in the USA, have more stringent restrictions for newer/younger drivers and bus drivers.

Social media consumption is at the highest levels ever. The typical US consumer uses three different platforms on a regular basis, with some accessing as many as seven different platforms! This is a clear indicator of the level of distraction people face, and some are tempted to access social media while driving.

Music streaming now accounts for over half of all music revenues; ironically, the most popular music streaming services are generating losses for themselves. How long will they stay in business? One interesting standout is Sirius/XM which continues to add subscribers and has been profitable for years, but they are a satellite-based broadcasting company, not a music streaming company as that term is commonly understood. Nearly 75% of new cars in the USA ship with Sirius/XM installed and require a subscription after a free trial period.

3.9: Macro Factors Summary

Considering all of these factors together, in the short term we expect the following.

- Consumers will continue to purchase and individually own vehicles and smart phones in greater quantities, migrate towards cities, and aggravate congestion, pollution, and safety issues in those cities.
- Automotive manufacturers will optimize around consumer preferences and pursue market share, seek incremental revenue and cost reduction opportunities, and respond to government mandates.
- Transportation departments will triage their infrastructure issues and pursue multiple technology, financial, and regulatory strategies to make incremental improvements in efficiency and safety metrics.
- Governments as a whole will face tough choices to meet economic development, energy supply, pollution, infrastructure, and public safety objectives. New taxation, tolling, and technology mandates may be required.

In terms of wireless technologies, we see all of them playing expanded roles in this dynamic. PAN (Personal Area Networking), WLAN (Wireless Local Area Networking), WWAN (Wireless Wide Area Networking), and GNSS technologies can address multiple objectives inside the car, on a city block, and across a region meaningfully.

The key question is how the dynamic between citizens (who are consumers, residents, voters, and potentially shareholders), auto manufacturers (who build products for consumers used on public infrastructure and seek profit for shareholders), and governments (who are keen on economic development and associated tax revenues to enable quality-of-life for residents and companies) will play out. Can these groups recognize each others' positions and agree on solutions? Who is the first mover to influence the others? How these discussions unfold on a regional basis will affect wireless technology adoption in vehicles.

4: SPECIFIC MARKET DRIVERS

In the previous section we looked at the automotive/truck/bus transportation environment from very broad perspectives; these are slower-moving trends, relationships, and issues creating opportunities for wireless technologies. In this section we look at more focused applications.

4.1: Engineering

Automotive history is filled with examples of companies and products over the past century. The great variety of brands and the unique designs they brought to market went through a long period of consolidation with some of them disappearing entirely and others purchased by larger companies.

The companies that survived, grew, and are still present today were some of the earliest adopters of vehicle platforms and assembly line techniques. Roughly speaking, a vehicle platform is a chassis/floorpan/suspension/powertrain design shared among multiple models in a given product lineup. Models are differentiated by exterior and interior design, choice of materials, level of amenities, and more. A few examples might include General Motors' Alpha platform, which underpins the Cadillac ATS, Cadillac CTS, and Chevrolet Camaro. Ford's C1 platform was used in their C-Max, Focus, and Kuga models, as well as Volvo C30, C70, V50, and S40 models, and Mazda Axela/3, Premacy/5, and Biante models. Volkswagen's A series includes Audi A3/Q3/TT, Volkswagen Golf/Jetta/Eos/Tiguan/Touran/Scirocco, and SEAT Leon/Toledo/Altea.

In addition to platforms and models, many include different levels of trim. The trim level or package group may influence specific design elements of the model, such as color selection, exterior lighting, interior materials, type of audio or infotainment package, and additional safety or convenience features. All told, we estimate there are approximately 5000 model/trim combinations, 1700 models, and 100-120 platforms in production globally across all automobiles, light/medium/heavy trucks, and buses/coaches.

During the design and development phase of a vehicle, many samples are made for test and verification purposes. Tracking the specific configuration of a vehicle and progression through test sequences can be a labor-intensive process requiring component access, reading serial numbers, and manually entering data into a database. To address this issue some manufacturers are starting to adopt RFID tags for tracking the specific configurations of test vehicles. Various suspension, powertrain, braking, interior, safety, and other components installed in a vehicle can be read as a group and stored in association with that vehicle. This greatly simplifies the configuration management process, helps control vehicle access to test facilities and public roads, and virtually eliminates the error rate associated with human data entry. There aren't many tags sold into these engineering development applications; they number in the tens of thousands compared to the 10 billion tags sold in total last year.

Recently we've seen more reports of manufacturers using their telematics platforms to capture data from test vehicles and transfer it to their engineering systems. We don't see this as a significant driver for incremental sales.

Source: Rfidautomobile

Illustration 6. Using RFID to Scan a Prototype Vehicle.

4.2: Manufacturing

The global automotive supply chain is extensive and feeds approximately 600 assembly plants globally; current production levels are nearly 95 million vehicles per year. An average automobile may have up to 30,000 individual components. The moving assembly line pioneered by Henry Ford is still the main method employed today for controlling material flow. Line configurations may include the buildup of engine, chassis, and body/trim separately, bringing the major subassemblies together for integration before proceeding to final assembly and inspection. Feeding these lines are steady streams of components and assemblies often in baskets, cages, and pallets from a substantial supplier base.

Modern lean manufacturing is focused on eliminating waste wherever possible. Different methods are often employed to work towards the goal of higher levels of value for the customer. The large quantity of baskets, cages, and pallets used for moving parts from the suppliers to the assembly line are starting to utilize RFID tags and readers. This is leading to reductions in lost cages and baskets, and it is starting to enable not simply just-in-time, but also pre-sequencing of components to reduce setup times. The magnitude of the opportunity for RFID tags just for transporting components is estimated in the tens of millions.

Source: Ford Motor Co.

Illustration 7. A Typical Assembly Line Station.

Tooling management is another application of RFID. Some manufacturers tag their manufacturing tools to track usage and speed inventory management. Given an automobile requires thousands of tools to produce all the required components, and each manufacturer is producing multiple models over an extended time period, the number of tags needed annually starts to approach a few hundred thousand – an order of magnitude higher than engineering applications.

RFID tags used in engines, seats, mirrors, bodies, and more provide configuration management, production line control, and visibility into production status. Among all the components receiving tags, the one component that has the highest potential for RFID tag volume is tires. The tire industry is working collectively to introduce four standards (ISO 20909, ISO 20910, ISO 20911, and ISO 20912) to make the application of technology consistent across the industry; the potential is there with nearly 1.5 billion vehicle tires sold annually. Work has been ongoing for years to embed RFID tags in truck and bus tires; at least one tire manufacturer has announced RFID is embedded in every tire it manufactures. By October 2018 the first two standards should achieve FDIS (Final Draft Industry Standard) approval and publication as international standards; the other two standards should reach DIS (Draft Industry Standard) approval. This might signal more widespread adoption of the technology all the way from rubber suppliers and tire manufacturers through their warehouses, distributors, and retailers. The volume of RFID tags we see in the automotive industry ranges from about 60 million a year (tooling, manufacturing, registrations, and electronic tolling) to up to 1.5 billion a year depending on how quickly tire manufacturers incorporate RFID in their products.

4.3: Transport

Up to 75% of new vehicles produced in North America are transported by rail initially; final delivery is handled via trucks pulling car hauler trailers. Larger vehicles, like medium-duty and heavy-duty trucks, as well as buses, are typically driven to their customers. The driver finds his way home with a car towed behind the truck or bus, or makes alternate arrangements.

The situation is different in Europe and China. In Europe, there are multiple railway systems with incompatible track and signaling systems. The idea that incompatible tracks made enemy invasion via rail impossible (and also prevented foreign competition from operating in your country!) is also a hindrance to economic efficiency within the European Union. Vehicles are primarily moved by truck, or in the case of larger vehicles, driven as per the USA. China uses its rail system for transporting passengers and bulk materials like coal; finished products such as automobiles are moved by truck as well. In fact, some of the provinces in China are starting to crack down on overloaded vehicle haulers and are defining standards for height, width, and length of these trailers.

A key point about vehicle transport is the fact it involves commercial vehicles, and drivers of commercial vehicles are subject to HOS (Hours-of-Service) regulations in the USA, Canada, Mexico, Europe and Australia. These countries are adopting ELDs (Electronic Logging Devices), smart tachographs, or EWDs (Electronic Work Diaries) to varying degrees. Dates vary from 2019 (USA and Europe) to 2020 (Canada) for these mandates and will drive GNSS, cellular, and DSRC technology adoption depending on which region is under discussion. Australia's position on EWDs was published this year (2018), but an actual mandate doesn't seem forthcoming. Mexico does not seem to have a plan for ELDs, but since some trucks regularly cross the border between Mexico and the USA, those drivers will have to adhere to the FMCSA (Federal Motor Carrier Safety Administration) ELD guidelines while in the USA.

China does not appear to have an hours-of-service mandate, nor does it seem to require logging data. Trucking in China changed radically in 1978 when China opened its borders to foreign trade and eliminated its state-run trucking company. Millions of Chinese farmers invested in smaller box trucks rated to handle 4 tons to 8 tons of load. Obtaining work is a manual process as they still go to open markets with jobs listed on chalkboards. They overload their vehicles, drive more hours than other countries allow, and face significant delays in long traffic jams. They undercut large container trucks with low prices and have stalled the development of more modern trucking infrastructures like those found in Europe, the USA, and Australia. Only in the past year have discussions about modernizing trucking in China started to occur.

More details will be discussed in the section on fleet management; this is just a brief mention of regional hours-of-service requirements and electronic logging requirements that will drive incremental technology sales.

Source: D'oh Boy (Mark Holloway)

Illustration 8. Vehicle Transporter.

4.4: Dealerships/Theft Recovery

While most dealership revenue comes from vehicle sales, most of the profit comes from trade-ins, financing, extended warranties, service plans, accessories, and maintenance/repair/inspection services sold to customers. It's here we see initial use and potential repurposing of vehicle telematics, first by the dealerships and later by the consumers.

DMS (Dealership Management Systems) are software applications that help automate most aspects of running a vehicle dealership. Cultivating and maintaining sales relationships, locating and managing inventory, drawing up sales sheets, processing financing, managing the service bays and parts department, titling and registering a car with the state DMV (Department of Motor Vehicles), sending promotions, and even time card/payroll functions are features of this software. Two of the key suppliers of DMS software have approximately 80% market share between them at this time.

Aftermarket and OEM (Original Equipment Manufacturer) telematics integrate with dealership management systems to help locate vehicles quickly for test drives. Telematics also helps with performing lot inventory checks and detecting stolen vehicles. A typical aftermarket telematics solution might be sold to a dealership on the basis it can make lot checks more efficient, and when an equipped vehicle is sold the dealer can then sell the installed telematics device as a theft tracking solution to the customer. The tracker and wireless subscription are offset by potential savings on the insurance policy. That same theft tracking solution can also be used to determine vehicle mileage and offer service department promotions to the customer as well through integration with the DMS. There are a number of aftermarket telematics companies with platforms accepting data from their own hardware as well as OEM hardware and integrating with DMS solutions. The utility value of these telematics cloud platforms combined with DMS is high for dealerships and even provides value to consumers when considering insurance rate offsets.

Source: Greg Gierdingen

Illustration 9. A Typical Dealership.

4.5: Registration/Identification

New and renewed vehicle registrations are typically contingent on proof of insurance and passing safety/emissions inspections, although the exact regulations vary from country to country. Older manual approaches to vehicle registration open the system to exploitation via loopholes. As an example, someone might purchase car insurance during the registration process and then cancel the policy after receiving a license plate sticker. Another example would be someone counterfeiting a license plate sticker, or even ignoring a required inspection. A thief might remove a license plate and apply it to a stolen vehicle for the purposes of driving it somewhere; a casual glance would suggest nothing is amiss on a stolen vehicle with a valid-looking plate. The end result is motor vehicle departments don't receive the full revenues due to them, unsafe or polluting vehicles operate on the roads, and vehicle theft is easier for criminals. Some policy and procedure updates improve enforcement of these issues, but don't catch all of them.

There are a number of electronic vehicle identification approaches either deployed or in test phase. South Africa uses RFID tags attached to license plates to automatically identify vehicles and verify registration. Bermuda uses RFID stickers attached to windshields for the same purposes. China has already started offering RFID stickers for windshields right now, and will make it mandatory for all vehicle registrations starting in 2019. India has mandated RFID tags on all new vehicles to promote cashless tolling and parking, but the infrastructure is not fully in place.

Beyond basic RFID tags, electronic license plates are just starting trials in California. The entire plate consists of a paper-white display driven by a telematics system including cellular and GNSS capabilities. In theory this display could show information such as inactive insurance, incomplete inspection, tampering/theft, and even public alerts in real time. Instead of relying on infrastructure to read RFID tags at known locations, this approach publicly displays the status of registration and reports vehicle location on its own, in theory making it easier for law enforcement to take action. We question the viability of electronic license plates as the high initial hardware purchase price, installation process, and monthly wireless subscription cost (all paid by the consumer) don't represent a fair trade for lower-cost methods. Individuals, like companies, like to "externalize costs" as well and will wait until legally required to do something differently.

China, India, and South Africa are guaranteed markets for vehicle-mounted RFID tags in the immediate future (approximately 30-35 million tags/year). It's important to understand the major problem each country is trying to solve. For China, road safety and traffic congestion is the stated purpose, although registration compliance seems like a strong justification as well. India has a goal of transforming itself into a cashless society, and RFID makes tolling, parking, fueling, registration, and other services possible without physical currency. South Africa has a high vehicle theft rate.

Source: Dickelbers

Illustration 10. South African License Plate.

4.6: Insurance

Private third-party insurance is very common, although some countries provide a road accident fund or public insurance company funded through vehicle registration costs and/or fuel taxes. New Zealand is an example country where a road accident fund provides compensation to people suffering losses on the road; additional third-party insurance is optional.

In general, insurance helps spread risk for a group of policy holders. The probability any one customer will suffer a loss is balanced against a population of others who won't. Insurance companies use statistical methods to set premiums for policies; these methods consider location, vehicle value, deductibles, individual driver history, age, gender, marital status, historical claim rates, desired insurance features, and other factors. Historically good drivers and bad drivers were lumped into the same pool.

Introduced about a decade ago, usage-based insurance changed the rules of the game by considering new parameters. PHYD (Pay-How-You-Drive), PAYD (Pay-As-You-Drive), and mileage-based insurance became new options for policy holders. Pay-how-you-drive refers to policy pricing based on the mechanics of operating the automobile – speeding, jerky steering, hard acceleration, hard braking, and other measurable parameters affect the pricing negatively. Pay-as-you-drive is a policy type that charges by the mile (or kilometer). Mileage-based pricing simply offers a lower rate if the total vehicle miles accumulated per year is below a threshold.

The adoption rate for usage-based insurance is currently about 15-20% in the United States. Italy is significantly higher, at 40-50%. The United Kingdom is also seeing some adoption after passing a law prohibiting different insurance pricing between men and women. However, China, Japan, and Brazil do not offer usage-based insurance, and the adoption rate is low single-digit percentages elsewhere. Relative to the number of registered vehicles globally, the adoption rate of UBI is still quite low overall. On one hand people cite privacy and security concerns; on the other hand, younger people are more willing to share information if it provides a better policy price.

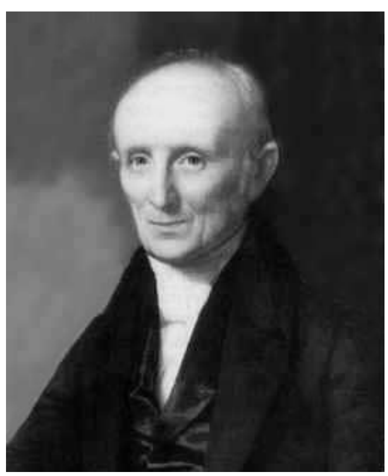
Three major implementations of UBI (Usage-Based Insurance) include:

- Aftermarket hardware: Some of the earliest UBI offerings from insurance companies included aftermarket telematics boxes requiring installation. These quickly gave way to dongles that plugged into vehicle OBD-II (On-Board Diagnostics) ports. In some cases, cellular connectivity provided data to the insurance company on a regular basis; in other cases, the dongle might capture data for a few months and go back to the provider for download and analysis.
- OEM telematic hardware: A few automotive OEMs are currently working with insurance providers to supply their telematics data directly from the car's embedded

modem. This option takes the most straightforward and efficient path from an engineering point of view, but involves difficulty with privacy concerns and a much more complex business model with entanglements between the OEM, dealer, and insurance company.

- Smartphone-based applications: The trend we see most frequently now is smart phone applications provided by the insurance companies themselves. This option addresses privacy concerns, as the user downloads and launches the application and therefore authorizes the application as with any other location-based service. The cost involved with a smartphone-based approach is also clearly minimal, as no additional hardware is required.

With a smartphone application the internal accelerometer and gyro sensors are used to monitor driver behavior. GNSS provides location and speed data. Data collected can be transmitted over cellular networks, or the data can be uploaded via Wi-Fi when in range of recognized access point. The providers of these apps make them configurable to help minimize data costs. In our view, this looks like the winning approach as it minimizes costs for all involved parties. The policy holder can restrict his data uploads to Wi-Fi if he wants, or leverage an “unlimited” data plan. The analytics firm will receive data directly from the app; there’s no need to buy data from an OEM or an aftermarket telematics provider. The insurance provider doesn’t have to provide any hardware to the policy holder, nor do they have to process any returned hardware. To confirm this, one of the pioneering insurance companies who introduced usage-based insurance to the USA recently stated in their annual report they continue to make progress moving away from hardware-based solutions. Another insurance provider also confirmed with us directly they still have a few hardware-based solutions in the field, but they don’t promote it anymore.



Source: East India Marine Society

Illustration 11. Nathaniel Bowditch, First American Insurance Actuary.

4.7: Financing/Repossession

There are a variety of financial products for taking delivery of vehicles. Cash purchases, loans, leases, and BHPH (Buy-Here-Pay-Here) financing have been around for quite some time. A new concept in the market is the idea of car subscriptions; this involves paying a monthly fee for the vehicle, insurance, maintenance, and repairs all in one bill.

When someone buys a car outright with cash, he takes delivery of the vehicle and ultimately receives a free and clear title showing his ownership. In every other financial product, though, another party has a substantial interest in the property. Depending on the arrangement and credit rating of the buyer, telematics may play a role in mitigating the risk of default or reducing the effort for repossessing the vehicle.

Buy-here-pay-here dealerships provide their own financing to consumers at elevated rates. The typical customer of a BHPH dealer has a poor credit history. The dealer agrees to sell the vehicle and provide financing to the customer, but as a condition of the sale and financing a GPS (Global Positioning System) tracking system with cellular connectivity and ignition cut is installed as well. If the consumer makes late payments or starts missing payments, the dealer can locate the vehicle, disable it, and send a repossession service to collect it. Typical default rates at BHPH dealerships are over 30%, and repossession fees range from $200 to $400 or even higher if more travel is required to retrieve the vehicle. A minimal tracking system that only takes 15 minutes to install with two wires starts to make sense to dealerships experiencing these conditions and is often included in the price of the vehicle. More than 2 million used vehicles per year are sold through these dealerships in the USA.

Leasing is an option available to consumers who like to change vehicles periodically instead of owning them. Nearly half of all passenger cars are leased in Europe, and nearly 30% of cars are leased in the USA. Leasing allows a customer to make payments against the anticipated depreciation of the vehicle. Conditions are included in most lease agreements stipulating mileage allowances, maintenance/repair requirements, and expectations around vehicle condition when it is turned in at the end of the lease. In our review of lease and loan arrangements, we could not find meaningful evidence of telematics used to enforce contract conditions, but that doesn’t mean they’re not used for repossession purposes.

Car subscriptions are a relatively new offering in the industry; instead of a customer handling his financing, maintenance, and insurance separately, all of these items are brought together in a single monthly bill. Along with the simplified billing, subscribers can swap out cars with a certain amount of notice to try something different. Car subscription services are more common at the high end of the market;

BMW, Mercedes-Benz, Porsche, Cadillac, and Volvo are some of the premium brands offering these programs. There are some programs at the lower end of the market, and a few independent ones as well. One argument for car subscription programs is it fills a slot between rental cars and leases for customers; another argument is the auto industry sees a fair number of lease vehicles turned in each year, and these are candidates for subscription programs. The number of subscribers in these programs is not well known at this point; with that said, it does appear telematics are commonly used to track the vehicles and also monitor driver behavior. At least one manufacturer is known to capture hard braking events, airbag deployments, and more.

Ultimately we expect to see both aftermarket and OEM telematics deployed widely in car subscriptions and buy-here-pay-here dealerships because the value of the assets is high and the risks of nonpayment or equipment abuse are much higher than average.

4.8: Rental Cars

The four major rental car agencies in the USA maintain a fleet of nearly 2 million vehicles currently. Europe has approximately another 1 million rental cars, and the rest of the world constitutes the remaining 1 million vehicles. On average, US-based rental fleets dispose of their vehicles after 13 months of use. Rounding this back to 12 months, or 1 year, then rental fleets represent 2 million new vehicles per year out of a total of 17 million vehicles sold in the USA, a considerable percentage.

Telematics plays a large role in rental car fleets. The major fleets all have clauses in their contracts indicating vehicles may report position, speed, fuel level, diagnostic codes, tire pressure, and other parameters of interest. In general the data is not used against customers unless a person drives a vehicle across a geographic restriction such as an international border. The connectivity is more useful in most cases to remotely unlock a car, or determine location to send assistance, or confirm a vehicle is dropped in an unattended location.

The rental car industry is not disappearing anytime soon; it's a guaranteed market for cellular and GNSS technologies.

Source: ArnoldReinhold

Illustration 12. Rental Car Center.

4.9: Ride Sharing

Ride sharing platforms connect for-hire drivers with passengers. They operate much like a taxi service in the sense a passenger is hiring a vehicle and driver for a certain amount of distance and time, except the process is streamlined with mobile phone applications for both roles. The centralized platform connects passengers with drivers and handles route planning and billing directly. In the spectrum of car ownership/usage experiences, taxis and ride sharing are probably the most temporary and most expensive options out of all of them on a per-mile basis.

The fact ride sharing applications reside on mobile phones is telling; why not have the driver's application reside in his infotainment system? While there might be some usability and safety considerations limiting this use case, we suspect the bigger issues include infotainment market penetration and infotainment platform proliferation. The average age for ride share vehicles is about 6 years old, and smaller fuel-efficient vehicles are generally preferred by drivers. Infotainment is generally an option on higher-end vehicles or higher levels of trim. Furthermore, when we consider the possible operating system choices (Android, Linux, QNX, and possibly a few niche players), the number of versions in the field, and the number of infotainment hardware platforms, guaranteeing an application will execute properly across a broad fleet of vehicles becomes costly.

It seems as though ride sharing will take advantage of vehicle-based cellular modems and GNSS solutions when the drivers are finally replaced with full level 5 autonomy. We don't see this happening broadly anytime soon, as legal and liability frameworks are not established yet, the technology is not transparent (not fully understood and explainable), and the costs for critical sensors are still high. Add to this the increasing urban traffic congestion caused by ride sharing services, and the public's general treatment of scooter and bicycle sharing services, and we think it will be awhile before governments and businesses agree on what is an acceptable product to be deployed in urban locations.

Source: Steve Jurvetson

Illustration 13. Autonomous Vehicle Computer System.

4.10: Diagnostics/Maintenance/Inspections

Just about every experienced mechanic will tell you, "cars used to be simpler." Maintaining a car well used to require a very analog and mechanical mindset. Carburetors would require tuning for big changes in altitude. Ignition systems needed their points and plugs gapped and the distributor timing set. People would regularly change oil at 3,000 miles, there were grease fittings on ball joints, and wheel bearings needed to be repacked regularly. Owners needed to be in tune with their vehicles and address maintenance religiously.

In more modern times these fundamental systems became computerized. Fuel injection has replaced carburetors. Electronic ignition systems require no adjustment. Oil sensors and onboard computers provide an estimate or remaining oil life. Some vehicles even report when brake pads are approaching minimum thickness, or when a light bulb is burned out. With all the sensors, actuators, and computers embedded in a modern vehicle, a local diagnostic tool is used with flowcharts and other test equipment to troubleshoot vehicle problems down to a root cause in the service bay. This tool might be a ruggedized piece of equipment from a large tool developer, or it could be program or app running on tablet or PC (Personal Computer). The connection to the vehicle is typically cabled to the OBD-II port, or it might be Bluetooth dongle.

Source: Losch

Illustration 14. Bluetooth Diagnostic Adapter.

Dealerships make most of their profit from service, so they are highly motivated to stimulate customers to service cars at their facilities. Selling the vehicle is just the beginning of a long relationship with a repeat customer (hopefully). As OEMs embed more telematics in their vehicles by default, we see evidence of the OEMs notifying their dealership network of vehicles needing predicted service, and then those dealerships proactively offering service to their customers with the intention of bringing repeat business back to them. In this way, the OEM offers value to the dealer and can ideally negotiate better terms in selling cars to the dealers.

4.11: Vehicle History

Vehicle history reporting is the process of collecting and storing information about a given vehicle, and generating a report for a potential buyer. The idea is to provide some insight about the condition of the vehicle beyond what is visibly seen. Purchase history, inspections, maintenance, theft and recovery, salvage titles, odometer tampering, and more can be captured from a wide variety of data sources.

Generally the company generating vehicle history reports sees revenue from dealers and individuals purchasing reports. The company provides incentive to their data sources by sending revenue for each new vehicle event entered into the database. Data sources could include dealerships, independent mechanics, oil change facilities, insurance companies, law enforcement, state inspection stations, junk yards, auctions, and others.

Almost all of the data sources are independent of the vehicle manufacturer, so while a vehicle may come with telematics by default, it's not likely the information is particularly useful to a vehicle history reporting service on its own. The value comes from the wide net cast across individual observers in the automotive ecosystem, not from a single source such as a telematics units. Much like emissions and safety inspections, the physical aspect of a vehicle's condition must be observed by a human and reported.

4.12: Concierge/Infotainment/Internet Services

Since the mid-1990s there's been a push to bring more connected services to automobiles. Starting with basic systems that enabled voice communications with a supporting staff of human operators, in the 2000s increasing microprocessor performance enabled more features and a graphical user interface in the car, and increasing communication bandwidth enabled media streaming and general Internet connectivity.

The earliest OEM vehicle telematics systems introduced the idea of a concierge service in the mid-1990s. With the press of a button a human would respond from a call center and the driver of the vehicle could make requests to locate addresses, order tickets to entertainment, provide directions to a destination, call for help, and more. In addition to the basic dedicated phone functionality and a staff of humans serving as the backend, the telematics unit included GPS-based location capabilities and connectivity with the vehicle databus. This enabled the unit to automatically place a call for help if the airbags were deployed, for example, and direct emergency services to the location of the vehicle. Europe formalized this safety feature with a mandate for all new vehicles starting this year (eCall). Remote diagnostics, dealer maintenance notification, theft recovery, and other services have become available as well. Multiple generations of this technology have been deployed over time to keep pace with upgrades in cellular standards, and this fundamental service is still available today.

The computing power available in microprocessors combined with the evolution of cellular standards led to the introduction of IVI (In-Vehicle Infotainment) systems in the early 2000s. Some of these systems were connected via cellular modules to back end servers; a few used Bluetooth to leverage a vehicle owner's cell phone using a dial-up networking profile. IVI systems typically provide a large LCD (Liquid Crystal Display) embedded in the dashboard with a touch panel or some form of dial/joystick control to navigate a user interface. To a certain extent these IVI systems replace humans at a call center as navigation functions are provided natively, although for a monthly premium some brands do offer human concierge services still. Early versions of IVI relied on local media (disc or memory card) to store maps; more recent versions now offer smartphone integration for displaying a phone's screen on the vehicle's dashboard. Approximately a quarter of new vehicles include high-end infotainment and smartphone integration with an expectation infotainment in general will increase over time to nearly half of new vehicles.

Mobile hotspot capabilities allow passengers to connect their own devices to the Internet. 4G LTE (Long-Term Evolution) network speeds and incremental pricing as low as $20/month for a vehicle owner makes it easy to keep families entertained while traveling. One of the key benefits of a telematics system providing hotspot capability is the improved link performance between the vehicle and base station versus a standard handset. The metal structure of a vehicle and certain coatings on glass mean the vehicle's cellular modem might see up to 8 dB of link improvement versus the handset in a cup holder. Police cars and fire trucks use cellular routers with laptops to access records. Charter buses and commuter buses are starting to provide in-vehicle Wi-Fi as well. Overall the market for in-vehicle Wi-Fi is dominated by private passenger car sales with a few major OEMs including it in nearly every vehicle they ship; the other markets are in the thousands to tens of thousands overall.

Source: TTTNIS

Illustration 15. Example In-Vehicle Infotainment System.

4.13: Safety/Efficiency/Infrastructure

We described the tension between automobile proliferation, congestion, and safety in the "macro factors" section earlier. Individual ownership of vehicles is still increasing, urbanization rates are still increasing, and this is leading to congestion on roads, pollution, and problems with safety. Both the automotive OEMs and the government have tried to address these problems in multiple ways.

Automotive OEMs traditionally have introduced new safety features to the market as options on some of their higher-end vehicles. Typically if a feature proved itself and could be reduced in cost through mass adoption, a government agency would mandate that safety feature in the interest of reducing collisions, injuries, and fatalities. Some examples of once-optional-but-now-standard safety features include seat belts, air bags, ABS (Anti-lock Brake Systems), vehicle stability control, and backup cameras. Soon automatic electronic braking systems and lane keeping systems may become mandated as well. The automotive OEMs have mostly focused on ways to prevent crashes and improve survival of crashes through better design and new features of their products.

In the United States, federal and state departments of transportation have also attacked safety and efficiency issues with road construction standards, signage and signaling standards, electronic signage, smart signals, and more. Attempts have been made to improve road utilization by controlling on-ramp flows during rush hours and having dedicated HOV (High Occupancy Vehicle) lanes. Toll roads, toll bridges and tunnels, and tolling around city centers provide additional lane capacity and discourage certain traffic patterns by using economic incentives to change behavior. The governments tend to focus on large-scale systems of traffic management.

Most of the solutions to date have been vehicle-centric or infrastructure-centric. V2X technology, however, promises to take an integrated approach to these safety, congestion, and pollution issues by creating an ecosystem for vehicles, roads, signals, signage, and tolling to speak with each other. DSRC, based on 802.11p, has gone through development, testing, and some deployment since 1999. Primarily found in electronic tolling applications, DSRC has been integrated in a limited number of vehicles to date. A few OEMs have announced they expect to bring DSRC to mass market in 2019 and beyond. Japan stands out as their ETC (Electronic Toll Collection) and ETC 2.0 systems have 60 million and nearly 3 million subscribers, respectively.

C-V2X is a competing technology to DSRC that has started to see some limited trials this year. To be clear, C-V2X utilizes the same spectrum as DSRC for vehicle-to-vehicle and vehicle-to-infrastructure communications, but can then leverage cellular spectrum to talk to a larger network. This is in contrast to DSRC, where the same range of spectrum serves all communications purposes.

The competition between these two technologies leads to a natural question – which one will win? On the one hand DSRC has been thoroughly tested for nearly 20 years, has seen healthy deployment in electronic tolling, and has several OEM announcements behind it. On the other hand, C-V2X shows a few technical advantages (longer range, scheduled messaging) and promises a roadmap of features leading to autonomous vehicles.

In our view, the individual governments in the major market regions probably have more influence over which technology is adopted than any other entity in the automotive ecosystem. The way each region allocates its spectrum, and any legislation specifying a technology, tends to automatically dictate a winner.

Europe has spectrum allocated for DSRC, has $1 billion invested in infrastructure initiatives, and has legislation in place for commercial vehicles requiring DSRC-enabled smart tachographs in 2019. Europe is home to one of the major automotive semiconductor suppliers with a DSRC solution. The momentum, investment, and government requirement for DSRC along with one substantial European OEM announcing DSRC integration in its vehicles leads us to believe this is the winning technology there.

China has spectrum allocated for C-V2X. It has no legacy DSRC infrastructure, but it does have Chinese wireless infrastructure and module companies ready to supply to its own country. There have been ongoing C-V2X trials in China, but very little activity related to DSRC. We have every reason to believe it's in China's interest to select C-V2X for itself; it's not likely they will switch to DSRC, nor will they field two technologies.

In North America there is spectrum allocated to V2V communications, and DSRC has been exhaustively tested in the 5.9 GHz band. C-V2X has not reached the same level of maturity and support from automotive OEMs. There are 22 different state-level departments of transportation who have written a letter to the FCC (Federal Communications Commission) requesting the spectrum remain allocated for DSRC. A few OEMs, including GM (Cadillac) and Toyota already have or will bring DSRC to market in their vehicles over the next few years. Experimental trials of C-V2X are happening in some states. In the meantime, a third group is lobbying to take some of the allocated spectrum and reuse it for another band of Wi-Fi. MEMA (Motor Equipment Manufacturers Association) has also submitted a letter to the FCC requesting the spectrum is preserved for DSRC. In a sense it's chaos with three applications chasing the same sliver of spectrum.

In summary, Europe likely has the most certain position with a combination of spectrum allocation (DSRC), mandates (smart tachographs), infrastructure, and OEM announcements (Volkswagen). China is likely next with a combination of spectrum allocation (C-V2X) and alignment with suppliers (Huawei, ZTE). However, they do not have any mandates nor are there any product announcements. The USA has spectrum allocated (DSRC) and OEMs have made product announcements (Cadillac, Toyota), but there are no mandates. There is some infrastructure deployed in individual states at this time.

At the end of the day, we expect the global market for V2X communications to be split between at least two different wireless formats.

4.14: Electronic Toll Collection

V2X initiatives can help with improving road utilization to a certain extent, but eventually there comes a time where additional infrastructure needs to be built. Depending on whether or not fuel tax revenues are keeping pace with road usage, toll roads, bridges, and tunnels may be used to add capacity without levying additional taxes on citizens.

As city centers become more crowded with vehicles, and as ride sharing services add to the traffic load on city streets, congestion and pollution become problems. Cities sometimes choose to levy a fee for entering certain zones around an urban center. Singapore and London are two examples doing this.

The motivation for electronic toll collection is to keep traffic moving as much as possible. Instead of stopping to pay a human in a booth, electronic tolling allows vehicles to continue moving and pay via electronic funds. This minimizes choke points and helps with traffic congestion.

The number of ETC subscriptions stands at roughly 200 million today.

- Japan has approximately 60 million subscribers using DSRC technology;
- The USA has about 70 million subscribers using active and passive RFID technology.
- Europe has the largest number of subscribers spread across multiple technologies including DSRC, GNSS, and ANPR (Automatic Number Plate Reader).
- China has mandated the use of RFID-based toll collection starting in 2019.

The market is expected to double to 400 million subscribers by 2025, with most of the growth in RFID technologies due to China's mandate. The overarching trend is to move towards passive RFID technology in new projects as read distances have improved, and the cost of the tag is very low thanks to not requiring battery-powered electronics. There are even examples of existing roads starting to offer passive RFID tags in place of active tags for free in the USA; this is a substantial cost reduction as active RFID tag batteries last about 4 years on average.

Source: Kalleboo

Illustration 16. A Toll Collection Gantry in Singapore.

4.15: AVL/MRM/Fleet Management

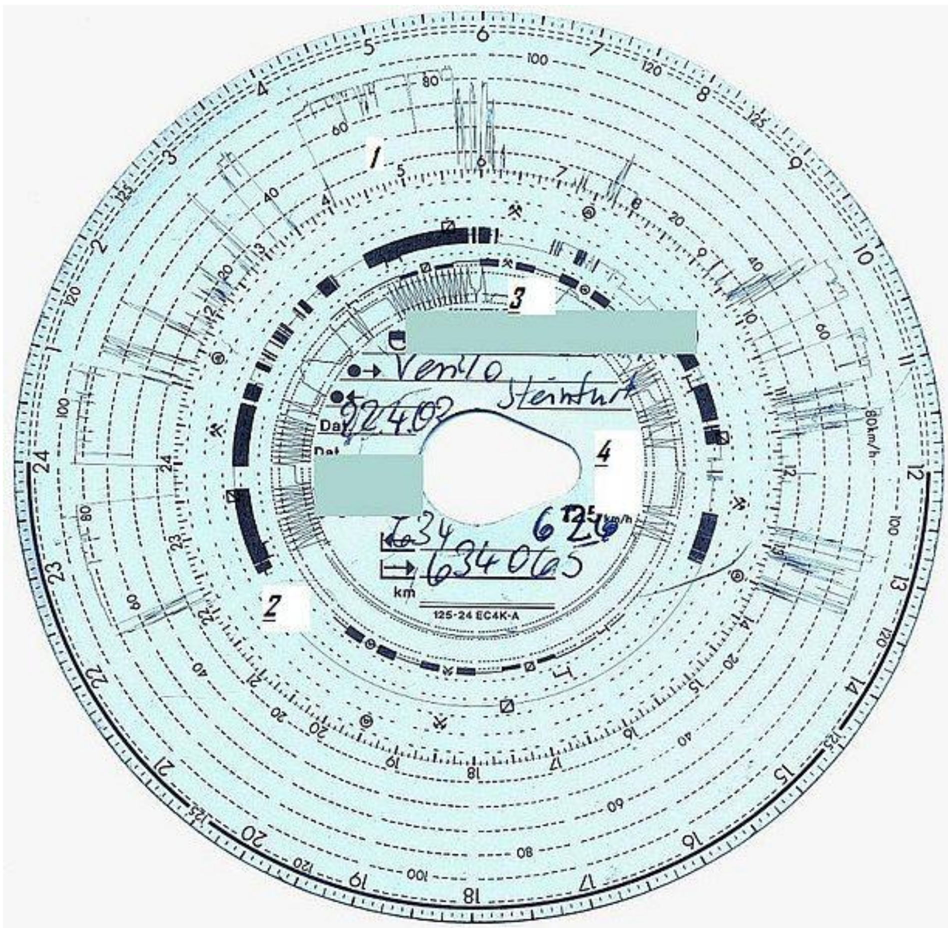
There are two main product types to discuss with respect to this market driver, AVL (Automatic Vehicle Location)/MRM (Mobile Resource Management) products, and HOS (hours of service) compliance products. The distinguishing characteristics include the type of fleet and the vehicles used.

AVL/MRM products are commonly used for service vehicles. Contractors, appliance repair services, home/yard/pest services, delivery services, utility repair, and other mobile workforce applications may use a MRM product. Typically the workforce and vehicles stay close to a base of operations and make multiple stops during a day to service multiple customers. The hardware typically includes a cellular/GNSS solution connected to the vehicle's databus and possibly connected to a tablet or phone running an application. A service's central dispatch can monitor and route individuals in their vehicles dynamically in response to changing conditions. Some degree of workflow integration is possible, as well. Monitoring can be as simple as knowing where the vehicle is at any time to enforcing rules for idling the engine and running the air conditioner for extended periods of time, reporting critical events, and insuring the vehicle is not used for personal purposes. The market for MRM solutions is somewhere around 300 thousand units per year in the USA with the current installed fleet of about 2 million.

Full-featured fleet management products are typically used in heavy commercial vehicles. Compliance with HOS regulations are driving this market. In the USA, the FMCSA has issued a mandate that all long-haul heavy truck drivers need to have ELDs (Electronic Logging Devices) installed in their vehicles by the end of 2019; at this moment in time, about 30% of the approximately 4.2 million heavy trucks operating in the USA do not have ELDs installed. This implies another 1.3 million ELDs need to be installed and operational over the next year to fully meet the mandate. These ELDs will incorporate GNSS and cellular technology to upload work hour data to the FMCSA's site for central processing. Some heavy commercial vehicles such as school buses and other vehicles below certain passenger counts, below certain weight limits, and/or traveling no more than a certain distance from a base of operations each day aren't required to install ELDs.

Europe also has a mandate requiring smart tachographs for their heavy goods vehicles by mid-2019. A tachograph is a device that monitors engine and road speed, and logs time the driver is on duty, active, resting, or off duty. Traditional tachographs used paper discs to record driver time over a 24-hour period. Digital tachographs replaced the paper disc with a driver ID and memory card. The new 'smart' tachographs will now incorporate Galileo GNSS for position and speed, and DSRC to communicate logs to road side infrastructure per regulation (EU) 2016/799. The mandate only applies to new registrations, or about 300 thousand vehicles per year.

Australia has a similar interest in monitoring drivers' hours of service and have created a framework for similar devices called EWDs (Electronic Work Diaries). A notice of final rulemaking has been issues, and the authorities are now accepting EWD products for approval. Unlike the absolute mandate issues in the USA and Europe, Australia's position is EWD adoption is voluntary even though the requirement to log hours and abide by the hours of service regulations is still required. This suggests other non-EWD methods may still be used by truckers to capture their time. With no approved EWDs available, it's unclear how quickly the market will pick up for them over the next few years.



Source: Sterkebak

Illustration 17. Analog Tachograph Disc Used for Recording Driver Hours.

4.16: Market Driver Summary

Market drivers for key wireless technologies include the following.

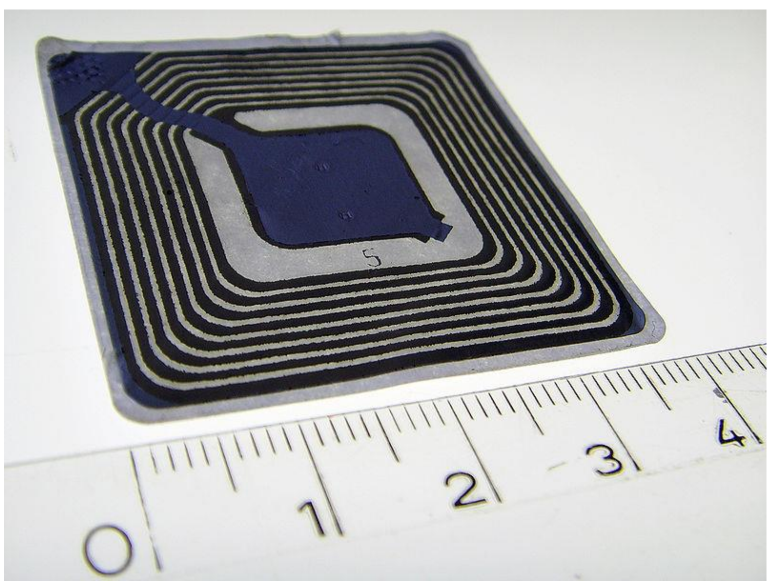
- RFID: RFID is predominantly driven by lean manufacturing techniques (tooling tracking and basket/cage/pallet tracking, material queuing), certain components (tires), vehicle registrations, and electronic toll collection. Out of all of these tires have the highest potential volume per year.
- Bluetooth: The main market driver for Bluetooth is the hands-free phone safety mandate issued throughout most of the world. Music streaming is also important due to the number of drivers who own smartphones. Virtually all vehicles come with Bluetooth these days.
- Wi-Fi: Typically Wi-Fi is driven by mobile hotspot capabilities incorporated in a telematics unit or a cellular gateway. Wi-Fi is occasionally used by some manufacturers for firmware updates as well. Some MRM/fleet management products include Wi-Fi for connecting to truck stop infrastructure.
- GNSS: Location technologies are driven by dealership lot inventories, theft recovery, usage-based insurance, repossession, rental car geofencing, autonomous vehicles, in-vehicle infotainment and navigation, V2X safety features, tolling, MRM, and fleet management.
- Cellular: Cellular connectivity is driven by OTA software updates, dealership lot inventories, theft recovery, usage-based insurance, repossession, rental car geofencing, autonomous vehicles, safety mandates such as eCall, in-vehicle infotainment and navigation, GNSS-based tolling, MRM, and fleet management.
- DSRC: DSRC volumes are driven by electronic tolling applications in Japan and parts of Europe. A few OEMs are incorporating DSRC for V2X applications, but they are not mandated to do so by any country at this time. Europe has V2X listed in its NCAP roadmap but European preference for DSRC is not clear, and European OEMs are starting to lean toward cellular.
- C-V2X: Cellular V2X volumes will be driven by the rate of Chinese V2X adoption in vehicles given the how the regulatory agencies around the world have allocated spectrum so far. No mandates exist for the technology yet, nor is it on any NCAP roadmap.

5: FORECASTS

In light of macro factors and specific market drivers discussed earlier, we now turn our attention to specific technologies and offer some perspectives and forecasts. We believe RFID, Bluetooth, GNSS, and Wi-Fi forecasts are relatively straightforward and won't spend much time discussing them; our main focus will be on DSRC, C-V2X, and cellular due to the dynamic market conditions and the higher value of these technologies.

5.1: RFID

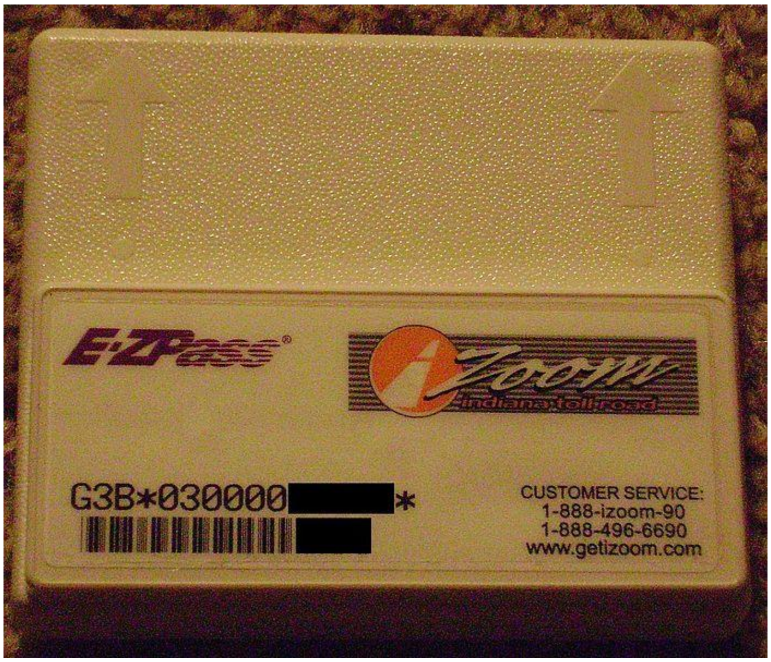
Passive RFID tag costs are now down in the $0.10range in high volume; their construction is relatively basic with a flexible substrate, printed antenna/capacitor, and bonded controller chip using roll to roll manufacturing for high volumes. A reader bombards tags with a field of energy, which the tag's controller chip then rectifies and uses as power to respond. The tag responds by changing its impedance following a specific protocol or pattern, and this pattern is detected as varying levels of energy transfer by the reader. Based on the sequence of energy levels, a data payload is reconstructed and then communicated to a host system using a serial interface.



Source: Maschinejunge

Illustration 18. Passive RFID Tag Manufacturing Example.

Active RFID tags are more expensive to produce in the $10-15 range. A lithium battery will typically be part of the design, along with a more sophisticated controller chip, passive components, circuit board with antenna, and enclosure. A reader bombards the tag with a field of energy, waking up the tag's controller chip. The controller uses the cell's energy to perform an operation and create a data payload. Once the reader's initial burst of energy subsides, the controller transmits a response back to the reader.



Source: Mrschimpf/Nate

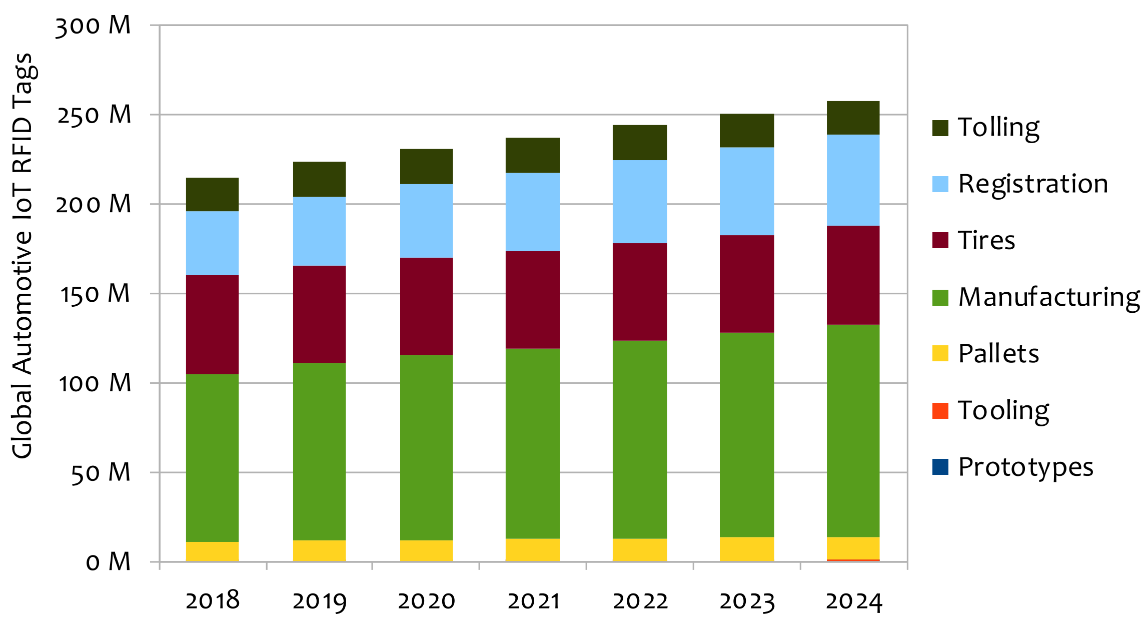
Illustration 19. Active RFID Transponder.

In addition to tags being passive or active, there are a variety of frequencies and protocols used depending on geographic location and industry application. In the automotive space passive UHF tags have the greatest penetration thanks to their combination of low cost and reasonable read ranges up to 10 meters. Active tags are used in some electronic tolling applications, but improvements in readers are enabling passive tags to be used in tolling now as well. This is a substantial improvement as battery life in active tolling tags is typically 4 years, so replacing active tags every few years becomes expensive for the vehicle owner. A passive tag is not only less expensive, but doesn't need replacement for the life of the vehicle.

In terms of applications and product volumes, we see the following.

- Digital prototyping, the process of tracking a prototype vehicle's ID and set of installed components during development, represents a volume of 30k-50k passive UHF (Ultra-High Frequency) RFID tags per year. This is based on how many new platforms and models are introduced each year (roughly 16% of available platforms and models), how many manufacturers are involved in such a practice, and how many vehicle samples and component samples are likely to be tested.
- Manufacturing tooling tracking has been touted by General Motors as a way to maintain its inventory of production tools spread across its supply base; we expect other manufacturers either are or will follow suit soon as multiple manufacturers draw from the same supply base. Based on the number of production tools needed for platforms and models on an annual basis as well as this practice spreading to other manufacturers, we anticipate 80k-100k passive UHF tags per year now growing to possibly 400k tags per year over the next 5-6 years.
- Based on the number of automotive assembly plants globally (about 600), the annual production volume of vehicles (about 95 million now), average complexity of a vehicle (30,000 parts), this represents a large number of pallets/bins/containers needed for moving all this material. We expect there is market for about 10-15 million passive UHF tags per year over the next 5-6 years.
- Different manufacturers are adopting RFID in their production processes to varying degrees. Tags for paint and finishing, engine production, seat/mirror/interior configurations are used to varying degrees. Some manufacturers use multiple tags; others use none. We estimate on average there is at least one tag per vehicle produced for both passenger cars and commercial vehicles, so the market for passive UHF tags in this space roughly follows our forecast for vehicle production – 95 million to 120 million vehicles annually over the next 5-6 years.
- Passive UHF RFID use in tires is increasing. Kumho has been placing tags on all tire products since 2013; this represents about 35 million tags per year. Michelin announced it has included RFID tags in all commercial truck tires since 2017 along with BFGoodrich. This represents about 20 million tags per year. When the tire industry ratifies its ISO standards for RFID technology, we may see more participation. Note that the commercial trucking business can justify RFID on tires more easily than passenger cars and light duty trucks – services who leverage RFID to track commercial truck tires are able to reduce their emergency service requests and save money, easily justifying the inclusion of the tags to begin with. The relationship between passenger car owners and tire retailers for service is not as strong or financially driven.

- Passive RFID is now mandated in China, India, and South Africa for new vehicle registrations. The total market appears to be ~35 million vehicles in 2018 growing to ~50 million vehicles in the next 6 years.
- RFID tags are used for electronic tolling predominantly in the Americas and India. North America should see growth from ~90 million subscribers today to ~120 million subscribers in the next 6 years. South America should see growth from ~15 million subscribers to ~30 million subscribers. In November 2017 India had roughly 600k ETC subscribers; since then the government has made passive ETC RFID tags mandatory on all new vehicles sold, so tag growth is expected to follow vehicles sales volume closely.



Source: Mobile Experts

Chart 6. Projected Global RFID Tag Shipments by Application.

* Registrations includes China, India, and South Africa. China and India registrations double for toll collection as well; South Africa is a few percent of the total.
* Tolling includes North America and South America; for a total in RFID tolling add in registrations for China and India.

5.2: Bluetooth

Bluetooth is a short-range wireless PAN technology operating in the 2.4 GHz ISM (Industrial Scientific Medical) band. It uses frequency hopping to minimize interference with other radios and GFSK (Gaussian Frequency Shift Keying) modulation. Over the last 20 years the technology has introduced additional modulation schemes enabling higher data rates up to 3 Mbps, and more recently it has also introduced low energy, broadcast, and mesh network capabilities. With Bluetooth 5 new options for trading connection range against energy consumption are now available; these are in addition to the traditional Class 1/2/3 (100 m/10 m/1 m) designations and ranges.

Application-level protocols called profiles exist above the basic radio, baseband, link management, and link control and adaption layers in the radio firmware stack. There are several profiles available, but the automotive industry only uses a few for basic hands-free calling, messaging, and media streaming use cases. Some of these profiles have existed nearly as long as the base Bluetooth technology; a subset of commonly used profiles is shown below.

Bluetooth Profile	Description	Original Date	Latest Date
A2DP	Advanced Audio Distribution Profile	2003-05-22	2015-07-14
AVRCP	A/V Remote Control Profile	2003-05-22	2015-12-15
DUN	Dial-Up Networking Profile	2001-02-22	2012-11-06
HFP	Hands-Free Profile	2006-03-14	2015-12-15
HSP	Headset Profile	2001-02-22	2008-12-08
MAP	Message Access Profile	2009-06-04	2017-06-27
SPP	Serial Port Profile	2005-08-15	2012-07-24

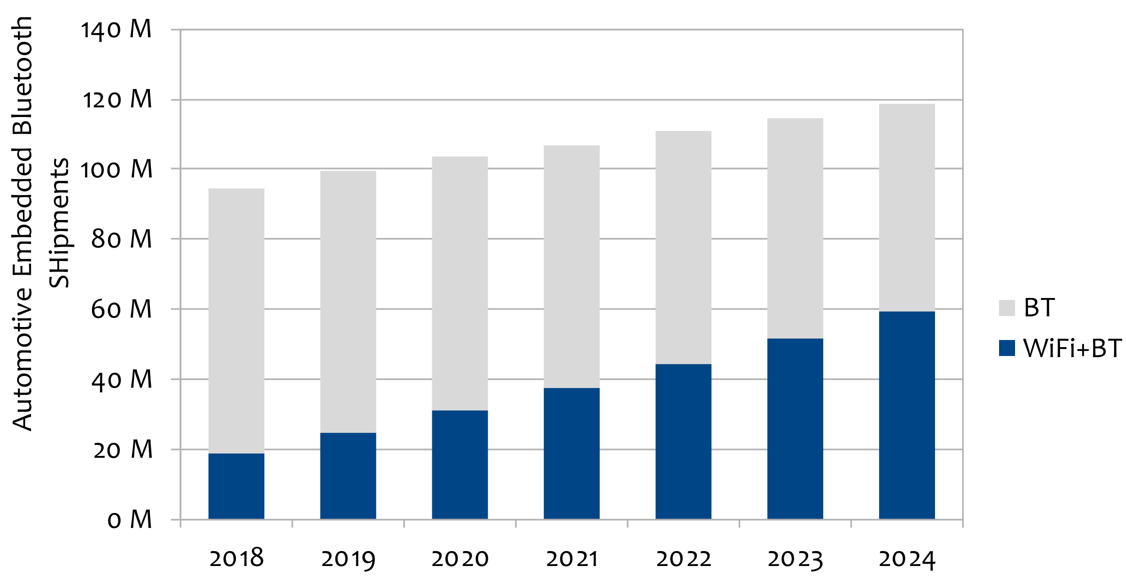
Source: Mobile Experts

Illustration 20. Bluetooth Profiles Used in Automotive Applications.

In terms of market drivers, all of the countries in our study have laws against handheld use of a phone while driving. Mobile phone penetration is nearly 100% of the population, and nearly two thirds of the population has smartphones. Because of this we see nearly every new vehicle offering Bluetooth connectivity and hands-free calling; even commercial vehicles like heavy goods trucks include Bluetooth today. Streaming music from a phone from either a personal collection or from a streaming service is simply an easy additional use case once the hardware is in place for hands-free calling and messaging.

The vast majority of vehicles are shipping with Bluetooth 4 today; only a few older vehicles are still using Bluetooth 3. Bluetooth 5 suppliers are starting to see inquiries

from Tier 1s and OEMs. Our overarching sense is that the version of Bluetooth is not so important as which profiles are supported in the software. The Tier 1s and OEMs will continue to architect and select devices based predominantly on cost.
The market for standalone Bluetooth radio chips is shrinking; smartphone integration and mobile hotspot features are driving growth in Wi-Fi+Bluetooth combo chips. With anticipated growth in mid-level infotainment offerings and more OEMs announcing mobile hotspot hardware installed by default, we expect shipment volumes to follow new vehicle production closely, but the partitioning to shift more towards combo devices over time.



Source: Mobile Experts

Chart 7. Projected Global Bluetooth / Bluetooth+Wi-Fi Combo Shipments.

5.3: Wi-Fi

Wi-Fi is the marketing name for IEEE 802.11 WLAN technologies. Over the past 2+ decades Wi-Fi has evolved, starting with a basic 2.4 GHz DSSS/FHSS signal providing 1-2 Mbps of throughput and quickly including a second 5 GHz band, OFDM modulation, wider bandwidth channels, MIMO, concurrent streams, and more. A simple comparison table showing the progression of standards is below.

Standard	Frequency	Bandwidth	Data Rate	MIMO Streams	Modulation
802.11	2.4 GHz	22 MHz	1-2 Mbps	n/a	DSSS, FHSS
802.11a	5 GHz	20 MHz	6-54 Mbps	n/a	OFDM
802.11b	2.4 GHz	22 MHz	1-11 Mbps	n/a	DSSS
802.11g	2.4 GHz	20 MHz	6-54 Mbps	n/a	OFDM
802.11n	2.4/5 GHz	20/40 MHz	Up to 288/600 Mbps	4	MIMO-OFDM
802.11ac	5 GHz	20-160 MHz	Up to 3466 Mbps	8	MIMO-OFDM
802.11ax	2.4/5 GHz	20-160 MHz	Up to 10530 Mbps	8	MIMO-OFDM

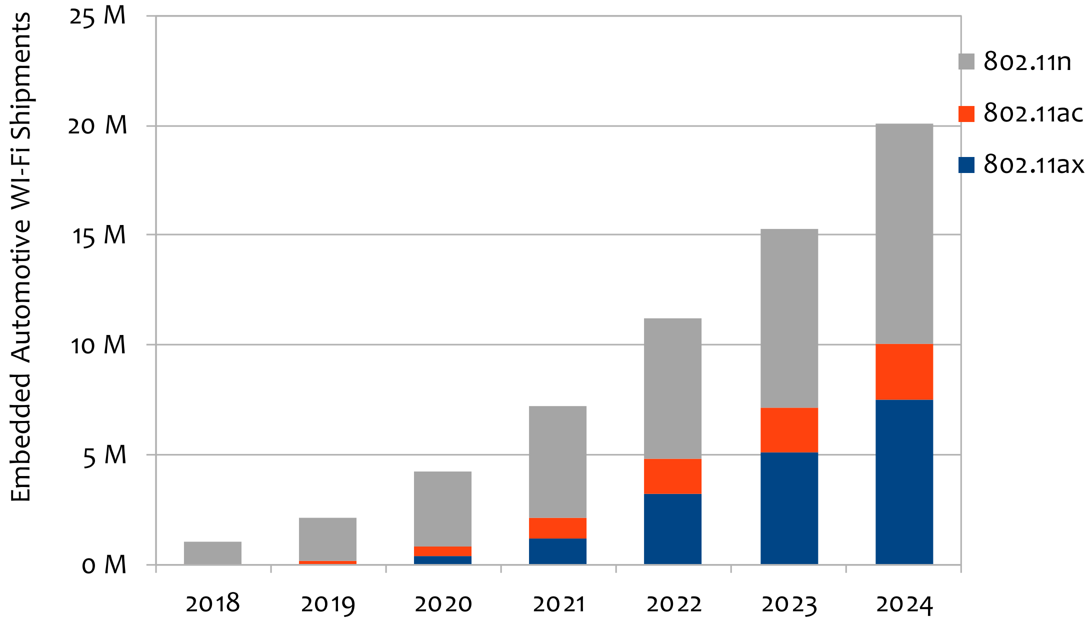
Source: Mobile Experts

Illustration 21. Comparison of 802.11 Standards.

In terms of automotive applications, Wi-Fi is mostly present to provide mobile hotspot capability in association with a cellular modem. Several OEMs offer an incremental data package on top of the core telematics packages so passengers in the vehicle can access mobile data via Wi-Fi in the vehicle. In addition to consumer vehicles, mobile hotspot functionality is commonly deployed in first responder vehicles, charter buses, and some AVL/MRM applications in support of workflows.

Current Wi-Fi deployments typically use the 802.11n standard, and match Category 4/6/9 cellular modem throughput pretty well. One market driver that is changing this, though, is the introduction of wireless smartphone integration. One of the major smartphone operating systems has explicitly called out 802.11ac to support its flavor of integration with in-vehicle infotainment systems, and BMW was the first OEM to bring it to market this year. In lieu of a USB cable, the infotainment head unit uses Bluetooth to pair with the phone initially, and then configuration information and credentials are exchanged with the phone so the primary link between the infotainment system and the phone moves onto Wi-Fi. Using Wi-Fi in place of a cable is convenient, but it does consume more power than cable or Bluetooth alternatives. Because of this, BMW also includes wireless charging based on the Qi standard.

With only one smartphone manufacturer driving 802.11ac requirements into the vehicle at this time, our view is the majority of 802.11 shipments will support the ‘n’ standard for the near term. Luxury cars will be the first to support 802.11ac because cost is less of a factor in this segment, and the technology will make its way into the premium tier infotainment systems from several OEMs over time. The majority of the volume will be driven by OEM installations.



Source: Mobile Experts

Chart 8. Projected Wi-Fi Shipments, by standard level.

5.5: Cellular

Earlier we identified multiple market drivers for cellular technology in vehicles; a list of applications with qualitative requirements is shown below.

	Event Rate	Update Rate	Latency Sensitivity	Data Quantity
Dealership Lot Checks	Daily	1/Day	Low	Small (kbps)
Theft Recovery	Daily/On Demand	1/Day to 1/Second(s)	Low	Small (kbps)
Repossession	Daily/On Demand	1/Day to 1/Second(s)	Low	Small (kbps)
Usage-Based Insurance	Per Trip	2-3/Day	Low	Small (kbps)
Rental Policy Compliance	Per Trip	2-3/Day	Low	Small (kbps)
eCall	On Demand	1/Event	Medium	Small (kbps)
V2X (V2N)	Per Trip	1/Second(s)	Medium	Small (kbps)
Concierge	On Demand	1/Event	Medium	Small (kbps)
Maintenance/Diagnostics	Per Trip/On Demand	1/Day	Low	Small (kbps)
Firmware Updates	On Demand	1/Event	Low	Large (Mbps)
Media – Music Streaming	Per Trip	1/Seconds	Medium	Medium (kbps)
Media – Video Streaming	Per Trip	1/Seconds	Medium	Large (Mbps)
Mobile Hotspot	Per Trip	1/Seconds	Medium	Large (Mbps)
Navigation	Per Trip	1/Minute	Medium	Medium (kbps)
Tolling	Per Trip	A Few/Day	Medium	Small (kbps)
Fleet Management (inc. MRM)	Per Trip	1/Event	Low	Small (kbps)
Autonomous Vehicles (Level 5)	Per Trip/On Demand	1/Event to Continuous	Low to High	Small to Large

Source: Mobile Experts

Illustration 22. Automotive Cellular Applications and Characteristics.

From the table shown in Figure 27, we can make a few observations.

- The majority of applications generate and consume very little data, and are not sensitive to reasonable latencies (a few hundred milliseconds) in the network. Most of these applications are machine-centric, in the background, and only come to the forefront on demand, on a trip basis, or very infrequently. Even a 2G GSM/GPRS/EDGE data modem could work acceptably in these conditions. In fact, some aftermarket equipment providers for theft recovery and repossession continue to use 2G modems in their products due to the low hardware cost of the module and the broad coverage of remaining networks, and are still waiting for 4G Cat M1 networks to have roaming agreements and provide more coverage before switching their hardware designs to newer modem hardware.
- There are four user-centric applications driving higher data consumption, including music and video streaming, mobile hotspots, and navigation. Vehicle firmware updates can also require large quantities of data. These applications are adequately served with 4G LTE modem technology; the downlink rates and network latencies are substantially better and preserve the intended user experience with crisp user interfaces, fast web pages, and no gaps in media playback. However, 4G LTE will have capacity issues with

hundreds of cars, streaming video while stuck in a traffic jam… therefore migration to 5G is likely over time.

- We see one future application, autonomous vehicles, being served by either 4G LTE or 5G technologies. There are a number of architectural decisions driving this, including trends in intelligent transportation system networks and the design of robust algorithms for controlling vehicles. One possibility is autonomous vehicles will learn from each others' experiences; feedback from vehicles on the road will be processed centrally and new classification and control models will propagate back out to all of the vehicles, much like a broad firmware update to address a factory recall. In this case there could be about 2-4 GB of data going to each vehicle to update it, but there won't be much concern around real-time network latencies in the range of 50-100 ms. A 4G LTE or LTE Advanced Pro modem could service these updates.

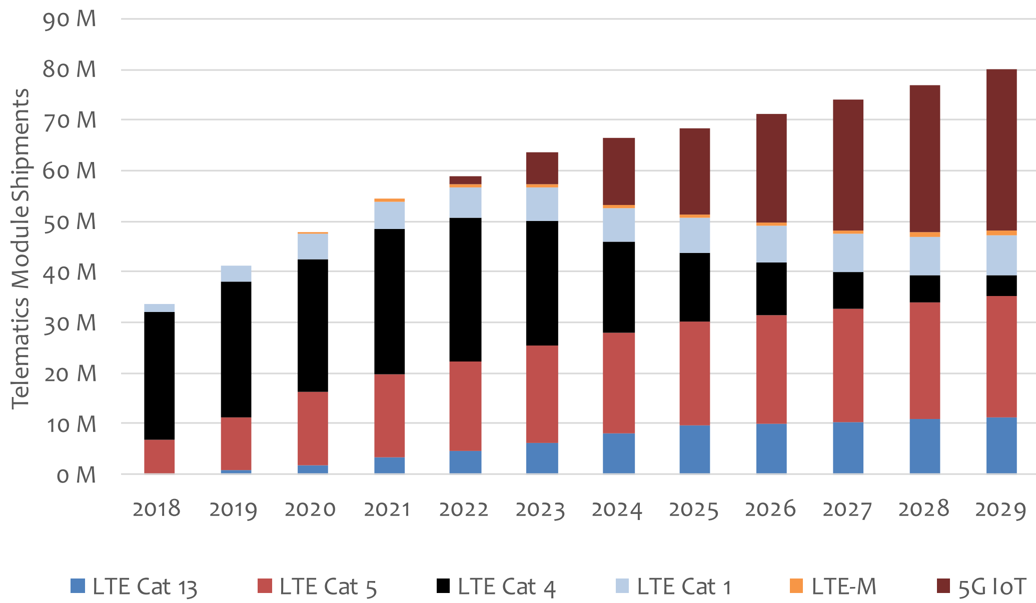
  Another possibility is the real-time operation of each vehicle will be fully networked; the basic safety cases of V2X technology will turn into large-scale "air traffic control" types of systems where every vehicle is reporting status and receiving commands to optimize traffic flow in urban centers. In this type of scenario, the data requirements might actually be quite low with a greater number of smaller packets, but the sensitivity to network latencies would be higher. So far, this central-control architecture is not the preferred view of the market, but it remains a possibility. Relationships between vehicles and transportation infrastructure are just starting to be tested with V2X technology. Mobile Experts considers this scenario to be less likely than the "on board" data sharing approach described above.

Automotive OEMs and aftermarket equipment suppliers take several factors into consideration when selecting a modem for a vehicle including the following.

- The expected use cases to anticipate needed data rates, generation of network technology, and coverage requirements.
- The hardware modem module cost.
- The extra cost of antennas, RF front ends, coax cables, and connectors.
- Carrier agreements for voice and data costs.
- Carrier network roadmaps, including sunsetting older network technologies.

In general, this means older chipsets are less complex and less expensive; mature networks have broader coverage; avoiding MIMO (Multi Input Multi Output) saves antenna, coax, connector, and additional RF (Radio Frequency) chain costs; older networks use fewer bands; etc. In the past, auto OEMs have not planned for the capabilities of a vehicle to change radically during its ownership (typically no new use cases). But today, the OEMs are starting to think like smartphone vendors or PC vendors, anticipating new use cases and requirements that will be created in the future. Optimizing only on cost is a way to guarantee a modem is obsolete when a country's carrier decides to shut off an old technology!

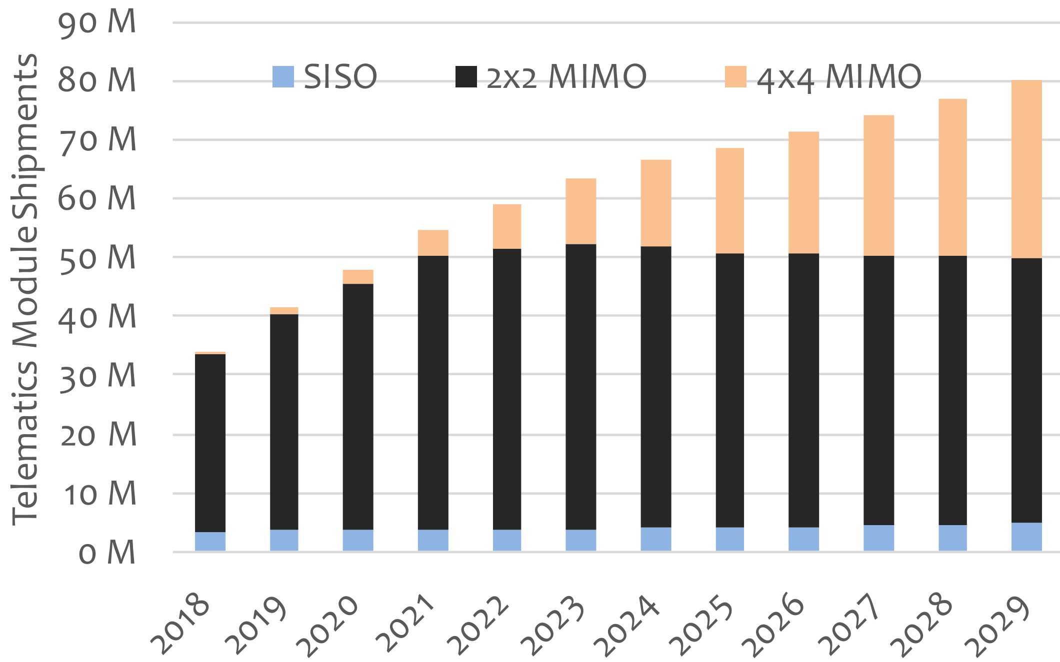
In our review of automotive-grade modem modules, the majority of LTE modules are Category 4 or 6. This makes sense as the raw data throughput of these modules is adequate for most of the data-intensive use cases. There are a few Category 9 modules available today, and we expect them to be selected more frequently in the next few years as more vehicles introduce mid-level infotainment systems.



Source: Mobile Experts

Chart 9. Projected Telematics Shipments, by cellular standard.

In general, we see 2 antennas for transmit and receive paths, not 4 or 8 antennas, to keep extra hardware costs under control. Most modem modules are installed inside the vehicle, not on the roof in an antenna assembly, as roof temperatures can exceed 100 degrees Celsius and cause filter performance to degrade.



Source: Mobile Experts

Chart 10. Projected Telematics Shipments, by MIMO level.

In terms of modem categories, the following shows maximum downlink and uplink speeds, and how many antennas can be supported. Cat 4, 6, and 9 modems follow a linear progression in max downlink speeds (150, 300, and 450 Mbps, respectively).

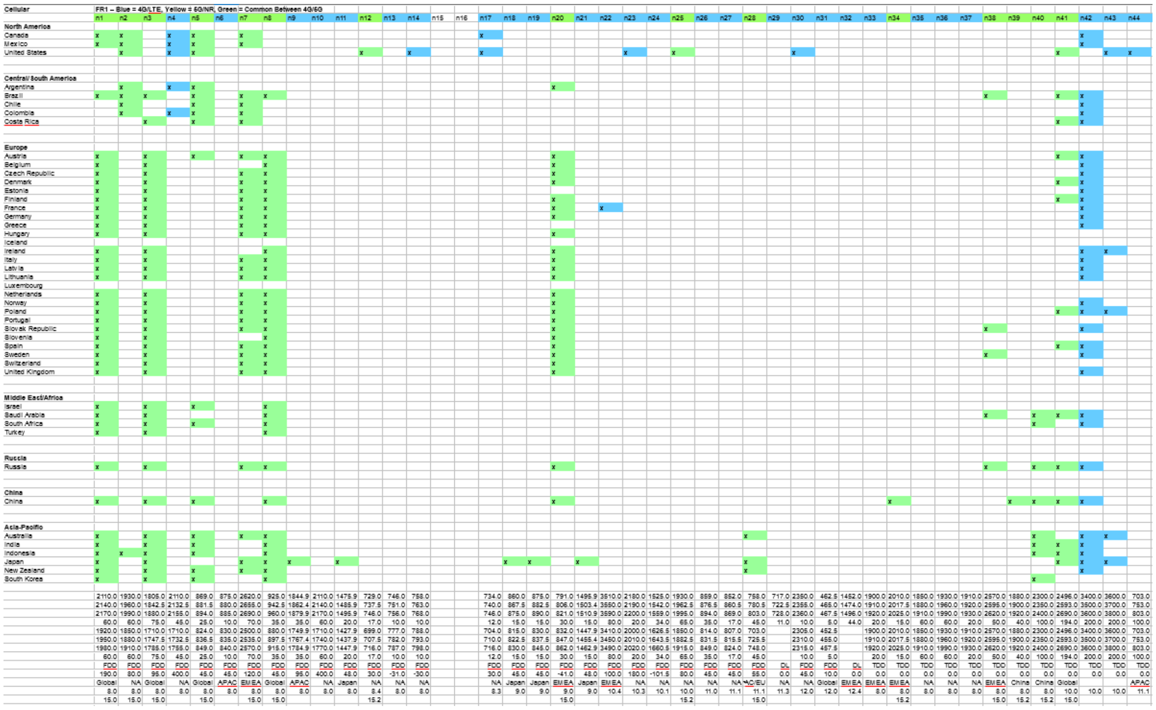
	Max Downlink (Mbps)	Max Downlink MIMO	Max Uplink (Mbps)
Category M1	1	1	1
Category M2	4	1	6
Category 0	1	1	1
Category 1	10	1	5
Category 1bis	10	1	5
Category 2	51	2	25
Category 3	102	2	51
Category 4	150	2	51
Category 5	299	4	75
Category 6	301	2 / 4	51
Category 7	301	2 / 4	102
Category 8	2998	8	1497
Category 9	452	2 / 4	51
Category 10	452	2 / 4	102
Category 11	603	2 / 4	51
Category 12	603	2 / 4	102
Category 13	391	2 / 4	150
Category 14	3916	8	9585
Category 15	749 to 798	2 / 4	226
Category 16	978 to 1051	2 / 4	105
Category 17	25065	8	2119
Category 18	1174 to 1206	2 / 4 / 8	211
Category 19	1566 to 1658	2 / 4 / 8	13563
Category 20	1948 to 2019	2 / 4 / 8	316
Category 21	1348 to 1413	2 / 4	301

Source: Mobile Experts

Illustration 23. LTE Modem Categories.

There are 13 carriers worldwide who have shut down or have plans to shut down their 2G networks by 2020. At least one large carrier in Europe plans to maintain its 2G network through 2025 given the installed base of M2M (Machine To Machine) applications it is servicing. This is creating challenging conditions for equipment suppliers who are facing sunsetting on older networks while waiting for roaming and coverage improvements for Cat M1 networks.

For the higher-bandwidth OEM applications, critical LTE band support by region is shown below; we summarize this graphic underneath it.



Source: Mobile Experts

Illustration 24. Active Regional Cellular Bands. (Note: See the Excel sheet for details)

In terms of regional band concentrations:

- Bands 1, 2, 4, 5, 7, and 17 are commonly supported in multiple North American countries.
- Bands 2, 3, 4, 5, and 7 are commonly supported in multiple South American countries.
- Bands 1, 3, 7, 8, and 20 are commonly supported throughout the European Union and Russia.
- Bands 1, 3, 5, and 8 are commonly supported in several Middle Eastern/African countries.
- Bands 1, 3, 5, 8, 20, 34, 38, 39, 40, and 41 are supported in China.
- Bands 1, 3, 5, 7, 8, and 28 are commonly supported in Asia-Pacific countries.

There are extra bands supported on a country-by-country and carrier-by-carrier basis, but there is a definite concentration of bands 1-8 and 20 usage, with the USA and Japan having multiple extra bands beyond this core set.

Will we see 5G technology in automobiles in the next 6 years? We see this as a regional question. In China, the 5G network at 2.5 through 4.9 GHz will be widely built out… at least 20 Chinese cities will be equipped with 5G by the end of 2019. Korea and Japan will also have widespread 5G networks in the 3-4 GHz bands by

2020. In these markets, we expect adoption of 5G radios in premium cars starting in roughly 2023.

1) While a few spectrum auctions have completed already, many of the 5G spectrum auctions are slated for 2018 and 2019, and a few extend into 2020. After spectrum is assigned it will take some time to establish networks with broader coverage. Some carriers can propagate software updates; others need to climb their towers and install new equipment. While carriers are making their plans and preparations today, it still takes some time on the order of months to a year to see some appreciable initial deployments. The initial focus will be on metropolitan centers with dense populations to bring in as many subscriptions as soon as possible. It will take even longer to increase 5G penetration over a wider coverage area.

2) There is greater overlap between sub-6 GHz 5G networks and 4G networks than between any previous generations of network technology. The actual speed increases from 4G to 5G are incremental in nature, many defined bands are common between 4G and 5G, and software plays a defining role in base station implementation. We don't see pressure to shut down 4G networks anytime soon.

3) The only use case potentially requiring higher downlink speeds and low latency is level 5 autonomous driving. We believe this use case won't see broad deployment for another decade or two as hardware costs are still high, the algorithms are not transparent/open to inspection/fully provable, and liability and insurance frameworks are in the early phases of discussion. For the other use cases we see, Cat M1 through Cat 4/6/9 capabilities are more than adequate.

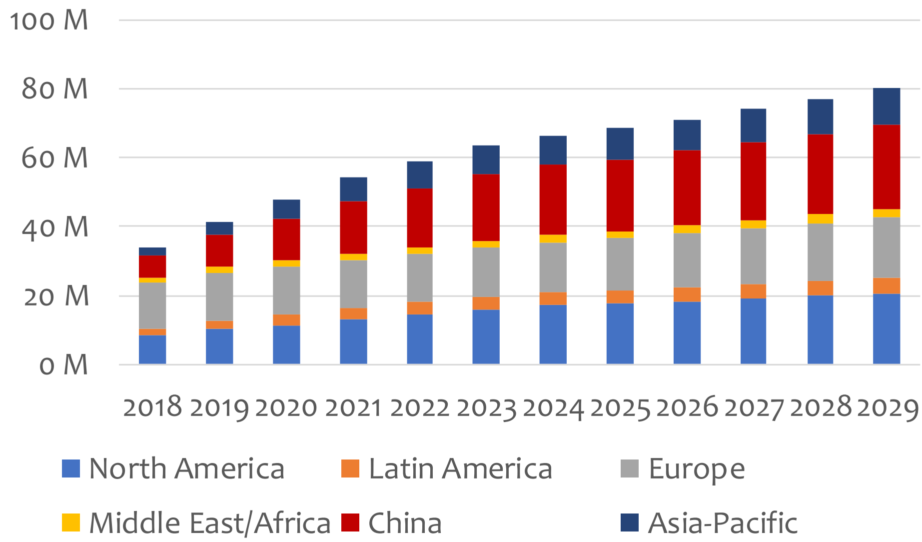
4) The initial emphasis for 5G is to show all the network speed it can muster and win handset customers to the technology. Most of the initial work will go into premium modems and SoCs which will cost more than established 4G chipsets. If Cat 4/6/9 modems are serving the industry well today, paying more for a 5G modem is unlikely, unless the operator offers a cheaper data plan. After the wireless industry's initial focus on handsets, the carriers' decisions on cost of automotive data plans will be critical to adoption.

In terms of modem forecasting, we consider anticipated vehicle production volumes, regional mandates, product positions and plans, competition within vehicle segments, adoption trends, and typical end application volumes. For example, in terms of mandates we see the following.

- The USA has a mandate that all commercial vehicles subject to hours of service logging must adopt ELDs by the end of 2019. At the time of this writing roughly 30% of the known commercial vehicles do not have ELDs installed yet.

- In Europe the eCall mandate took effect for all passenger cars and light commercial vehicles starting in May of this year.
- Russia has their ERA-GLONASS mandate which is similar to eCall; it took effect in January 2017 for all new vehicles.
- Turkey has mandated eCall for all new vehicles in 2018; Saudi Arabia will follow in 2019.
- China requires trackers on all taxis, buses, trucks, and tankers.
- India mandates trackers on all buses, school buses, ambulances, and public transportation as of April this year.

All of the top luxury car manufacturers are including modems with their vehicles, and several high volume OEMs are either shipping modems in all their vehicles or will be shipping modems in their vehicles soon. Other high-volume OEMs are offering modems in the top trim levels of their vehicles, but we expect a trickle-down effect into middle trim levels over time.



Source: Mobile Experts

Chart 11. Projected Telematics Modem Shipments.

In addition to the mandates and vehicle OEM positions noted above, fleet management (including mobile resource management) and theft recovery are high-value applications that help individual businesses optimize, maintain, and recover their assets. South America, in particular, has a high percentage of commercial vehicles tracked for theft recovery.

5.6: DSRC

DSRC commonly refers to a collection of communication, hardware, and software stack standards used to implement electronic tolling and V2X applications. DSRC is already in use for electronic tolling in Europe, Japan, and Australia, and there are multiple pilot programs testing V2X applications in the USA, Europe, Australia, and Japan.

DSRC is based on technologies described in IEEE (Institute of Electrical and Electronics Engineers) 802.11p; this standard was approved in 2010 and is based on a much older IEEE 802.11a WLAN standard from 1999. While 802.11p and 802.11a share modulation, channel coding, and number of subcarriers in common, 802.11p has half the channel bandwidth (10 MHz), half the data rates, half the subcarrier spacing, and twice the CP (Cyclic Prefix) interval and OFDM (Orthogonal Frequency Division Multiplexing) interval. A short comparison table is shown below.

	802.11p	802.11a
Channel Bandwidth	10 MHz	20 MHz
Data Rates	3, 4.5, 6, 9, 12, 18, 24, 27 Mbps	6, 9, 12, 18, 24, 36, 48, 54 Mbps
Modulation	same as 802.11a	BPSK, QPSK, 16QAM, 64QAM
Channel Coding	same as 802.11a	Convolutional coding rate: 1/2, 2/3, 3/4
Number of Data Subcarriers	same as 802.11a	48
Number of Pilot Subcarriers	same as 802.11a	4
Number of Virtual Subcarriers	same as 802.11a	12
FFT/IFFT Size	same as 802.11a	64
FFT/IFFT Interval	6.4 us	3.2 us
Subcarrier Spacing	0.15625 MHz	0.3125 MHz
CP Interval	1.6 us	0.8 us
OFDM Symbol Interval	8 us	4 us

Source: Mobile Experts

Illustration 25. Short Comparison of 802.11p and 802.11a parameters.

DSRC spectrum is allocated differently based on location and application currently.

	Spectrum	Purposes
USA	5850 – 5925 MHz	V2X
Europe	5795 – 5815, 5855/5875 – 5905/5925 MHz	Tolling, V2X
Japan	755.5 – 764.5 MHz, 5770 – 5850 MHz	Tolling, V2X
Australia	5725 – 5875, 5875 – 5925 MHz	Tolling, V2X

Source: Mobile Experts

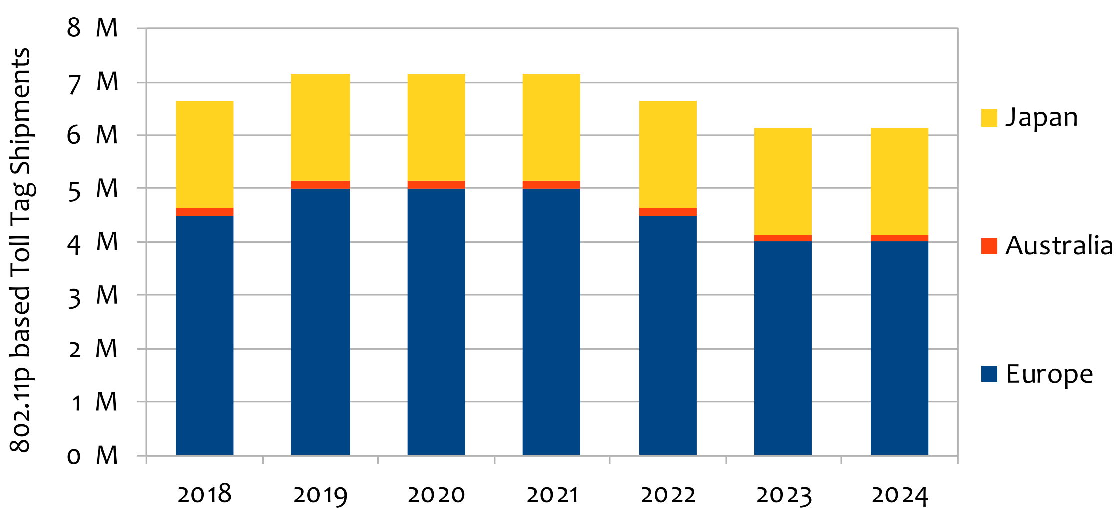
Illustration 26. DSRC Spectrum Allocations.

Tolling applications in the 5.8 GHz band are well-established already, although a unified standard for higher-layer protocols and payment processing hasn't existed in

Europe. It's not unusual for some truck drivers to have multiple OBUs (On Board Units) to pay tolls as they cross into different EU (European Union) member countries. The EU has issued directives and consultations on this issue since 2004; it looks like it is being resolved as multi-protocol OBUs for tolling are available for pre-order now. There are approximately 3.5 million commercial truck drivers in Europe who can benefit from newer multi-protocol OBU hardware.

Japan, on the other hand, is uniform in its deployment of DSRC for tolling. Their ETC system has nearly 60 million subscribers. ETC 2.0, a new version of ETC with enhanced information capabilities, now has approximately 2.5 million subscribers. The larger group of 60M+ users will begin a transition to ETC 2.0 in a few years as ETC 2.0 offers ITS (Intelligent Transportation System) messaging in addition to toll collection functionality, and the Japanese government is considering a pricing strategy that eliminates "withdrawal/re-enter" fees for exiting the highway and using a service station. This pricing advantage would only be available under the ETC 2.0 program. Japan has nearly 3500 RSUs (Road Side Units) deployed.

Australia has issued over 6 million DSRC-based tolling transponders to date for 16 different roads since the 1990s. Growth is expected to be low over the next 6 years.



Source: Mobile Experts

Chart 12. Projected 802.11p-Based Toll Tag Shipments.

In addition to electronic tolling in the 5.8 GHz band, DSRC is being used in the 5.9 GHz band and 760 MHz band for vehicle safety applications. Whereas Europe and Australia are using 5.8 GHz for tolling and 5.9 GHz for vehicle safety, Japan is using

5.8 GHz for tolling and some ITS roadside communications and 760 MHz for vehicle-to-vehicle safety.

Though DSRC-based V2X applications all start with the same 802.11p standard, there are regional variances in higher layers of the protocol stack. In the USA, for example, DSRC-based V2X relies on IEEE 802.11p, IEEE 1609.1-4, and SAE (Society of Automotive Engineers) J2735.

- IEEE 802.11p defines the lowest layer of the radio
- IEEE 1609.4 defines multi-channel coordination in the MAC layer
- IEEE 1609.3 defines network services
- IEEE 1609.2 defines security services
- IEEE 1609.1 defines application-level services
- SAE J2735 defines the application message set

In Europe, DSRC-based V2X is defined by the following.

- EN 302 663 is the base ITS-G5 standards
- TS 102 724 defines multi-channel coordination in the MAC layer
- TS 102 687 defines the DCC frameworks
- TS 103 175 defines the DCC management

Collectively these four standards are called ITS-G5 (Intelligent Transportation Systems - 5 GHz) and are similar to the combination of IEEE 802.11p and IEEE 1609.4, which are called WAVE (Wireless Access for Vehicle Environments). Additional European standards include the following to complete the protocol stack.

- TS 103 097 defines security
- TS 102 941 defines privacy
- EN 302 636 defines geo-networking and multihopping
- EN 302 637, TS 19 091, and TS 19 321 define V2X messages
- TS 102 539 defines the application layer

Australia tends to follow Europe when it comes to standards; they have already adopted the same spectrum and channel assignments.

Japan uses two standards in its protocol stack.

- ARIB STD-T109 references IEEE 802.11p for low-level radio PHY operation, and then addresses all other protocol layers within the standard itself. The ARIB standard is similar to the combination of IEEE 802.11p and IEEE 1609, so it is yet a third standard compared to WAVE and ITS-G5.

- ITS FORUM RC-013 defines the application layer message set; this is roughly similar to SAE J2735 in purpose.

In the last few years DSRC has been challenged by C-V2X to be the technology of choice for connected vehicles. One of the arguments provided by the C-V2X camp is their technology has a defined roadmap starting from Release 14 with the expectation the technology will continue to see evolution in Release 16 (and possibly beyond). In response to this challenge, DSRC proponents are now spearheading 802.11NGV, a next generation V2X technology compatible with 802.11p but offering more bandwidth, more range, and more efficiency. 802.11NGV has an active study group at this time.

In terms of DSRC forecasting for V2X applications, we consider the state of government, infrastructure, and auto manufacturers as shown below.

	Mandates	Safety Roadmap to V2X	DSRC Spectrum
USA	No	none	5.850-5.925
Europe	No	NCAP 2021/2023/2024	5.855-5.925 GHz
China	No	none	none
Japan	No	none	755.5-764.5 MHz
Australia	No	Use European NCAP 2018+	5.855-5.925 GHz

Source: Mobile Experts

Illustration 27. Government Factors Influencing DSRC Adoption for V2X.

None of the major market regions are mandating V2X technology in new vehicles at this time. Only the European NCAP has a roadmap showing development, release, and implementation of a testing program for V2X by 2024; Australia has decided to adopt Europe's NCAP recommendations as of this year. Four of the five major markets for V2X have spectrum reserved for DSRC V2X; only China has spectrum reserved for C-V2X at this time.

Infrastructure upgrades and pilot programs are happening across Europe, the USA, and Japan:

- In the European Union, 16 member states have shared their plan statuses with C-Roads. All have selected ITS-G5. ~675 RSUs are planned in 6 states in 2018/2019. The other states are expected to submit more details about their pilots this year. We estimate ~1600 RSUs deployed in total over the next 2-3 years.
- In the United States, the USDOT is sponsoring three studies in New York City, Wyoming, and Tampa Florida with a total RSU count ~470 units. Another 815 RSUs are attributed to Michigan, California, Minnesota, Utah, Arizona, and Pennsylvania. While Colorado is currently operating pilots as part of the

Smart70 and Smart25 programs, their RSU count could reach up to 1000 units. There is an open SPaT (Signal Phase and Timing) Challenge sponsored by the NOCoE (National Operations Center of Excellence) which promotes RSU deployments to show auto OEMs the country is serious about V2X technology; current there are 216 signals operating and another 2200 planned over the next 2-3 years. In total there is potential for up to ~4500 RSUs deployed over the next 2-4 years.

- In Japan the 5.8 GHz ETC/ETC 2.0 system has nearly 3,500 RSUs deployed already. The purpose of 760 MHz DSRC is for V2V communications, not ITS communications.

The following auto manufacturers have made announcements signaling DSRC deployments; we don't see any other commitments announced by other OEMs at this time.

	Now	Future
Cadillac	CTS (since 2017 in USA)	Also in a high-volume SUV by 2023
Toyota	Crown, Prius, Lexus RX (since 2016 in Japan)	USA start in 2021; most vehicles mid-2020s
Volkswagen	none	Europe start in 2020

Source: Mobile Experts

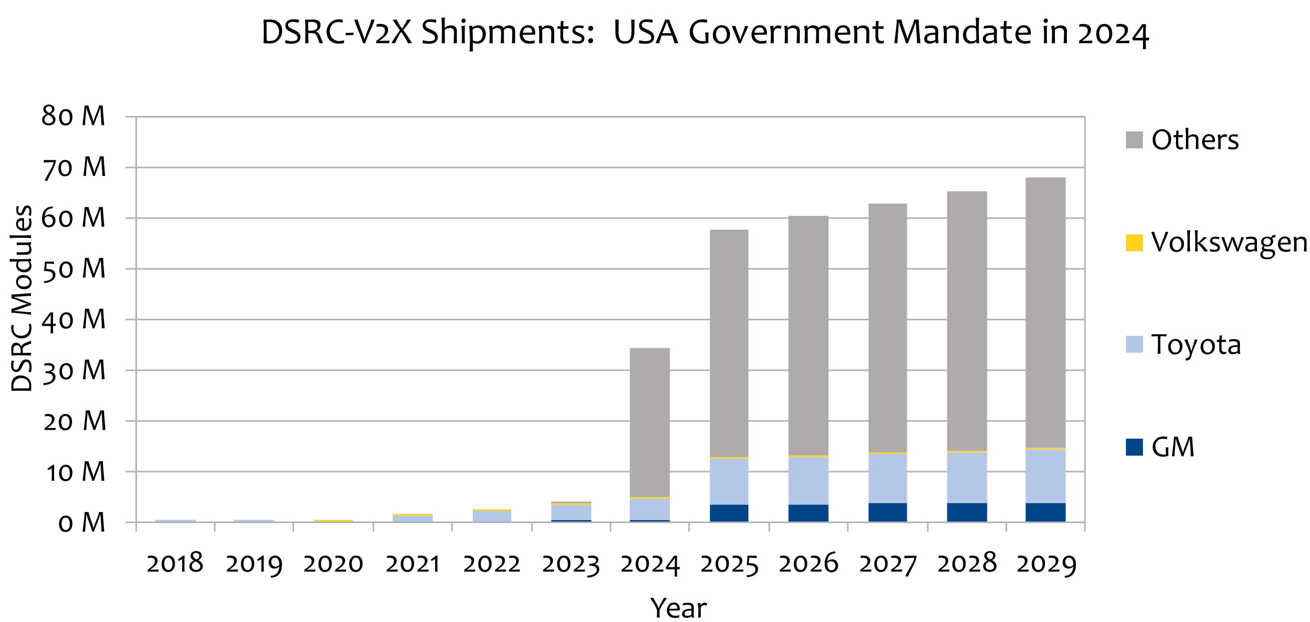
Illustration 28. OEMs Indicating DSRC Adoption for V2X.

We see the DSRC-based tolling situation improving in Europe with multi-protocol OBUs, and we see the real possibility of Japan's citizens accelerating their migration to ETC 2.0 if the government introduces some exit/re-entry fee incentives. The C-Roads initiative in Europe is showing real plans around RSU deployments based on ITS-G5 standards, and the USA's SPaT Challenge is showing more responses from local and state governments than originally anticipated. Australia is following Europe's lead in terms of spectrum allocation and NCAP roadmap for V2X. Japan has an installed base of vehicles using 760 MHz V2V communications now. At least two OEMs have announced intentions to bring DSRC-based V2x to mass production in the next two years in the USA and Europe. Challenges from the C-V2X camp with respect to technology roadmaps are seeing a response in the form of an 802.11NGV study group.

Note that the market for DSRC modules is highly dependent on government mandates. Without a government mandate, the OEMs have very little commitment to the technology. After all, if one major OEM introduces V2V technology, it's useless in terms of safety enhancement because most other cars won't have DSRC connectivity. The government is the only way to force the market into sharing this technology. One key decision point is in the United States, where a DSRC mandate was planned by President Obama's administration in 2015, but a change in government with President Trump derailed the new regulation.

In the USA, Europe, Australia, and Japan, DSRC has a lead at this time over C-V2X for V2X applications. National governments and local municipalities have allocated their spectrum, initiated their ITS programs, and have started their infrastructure deployments. A few OEMs are shipping or have plans to ship DSRC-based solutions soon. No region wants two technologies for the same purpose; volume shipments of vehicles could lock a region into a technology quickly. Changing represents modifying programs and extending budgets while the transportation departments are motivated to reduce crashes and fatalities as soon as possible. We expect autonomous vehicles to be deployed broadly in a distant future, not in the next few years; they're not a substantial market driver for a technology choice at this time.

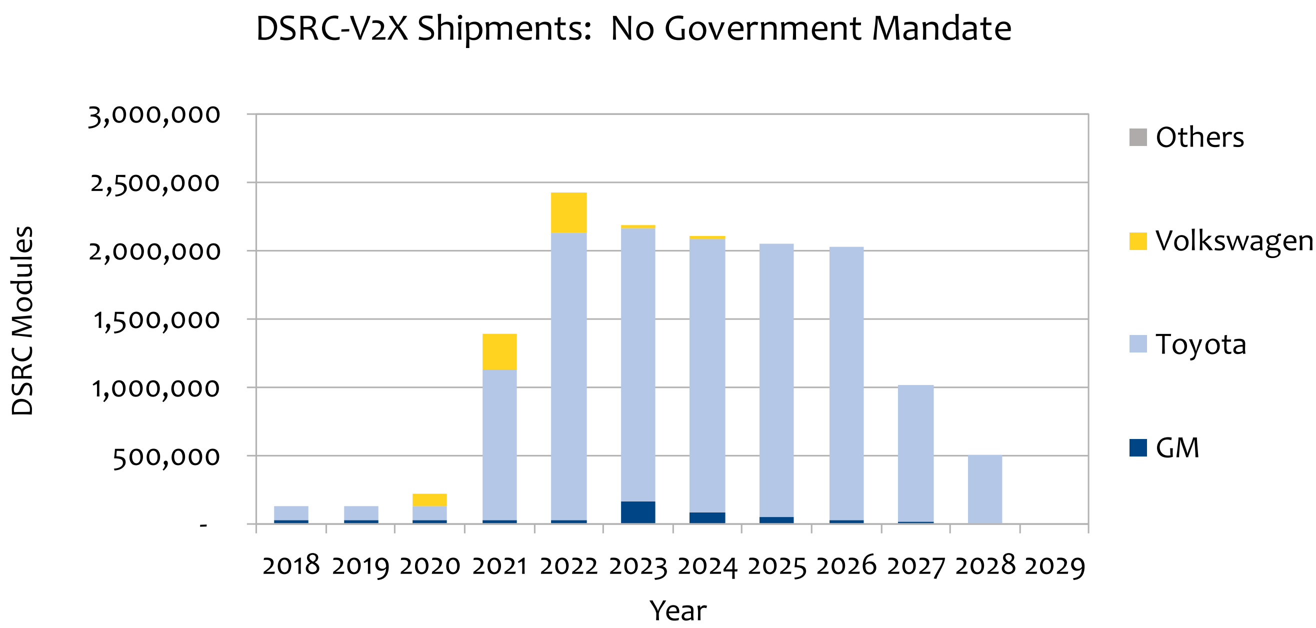
We have forecasted the DSRC market in two ways: First, we show DSRC-based vehicle V2X shipments each year, assuming a USA government mandate takes effect in 2024 (note that the assumption is that the politics will enable the regulatory agency to move forward again in roughly 2021, leading to a mandate in 2024).



Source: Mobile Experts

Chart 13. Projected OEM DSRC-Based V2X Shipments.

Our second scenario assumes that no USA government mandate occurs, so the 802.11 based market in the USA does not appear, and other regions such as Europe and Asia are more likely to migrate to LTE or 5G technology for V2X applications.



Source: Mobile Experts

Chart 14. Projected OEM DSRC-Based V2X Shipments, with no USA mandate

Overall, we believe the DSRC future hinges on the policy of the US government.

5.7: C-V2X

Cellular Vehicle-to-Anything (C-V2X) is a competing technology to DSRC for V2X applications. It traces its origins to 3GPP (Third Generation Partnership Project) Release 12 D2D (Device to Device) sidelink technology, which initially didn't meet vehicle requirements due to high central scheduling latencies. In 3GPP Release 14 C-V2x was formalized, adding more modes of operation to the sidelink interface reducing those latencies. Future 3GPP Release 16 is expected to introduce 5G NR (New Radio) technology to the sidelink interface, but at the same time remain backwards-compatible with Release 14.

In addition to direct communication between vehicles, other vehicles, and roadside units, C-V2X introduces the notion of using cellular wireless infrastructure to indirectly communicate over longer distances. Just to be clear how DSRC and C-V2X handle V2V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure), V2P (Vehicle to Pedestrian), and V2N (Vehicle to Network) scenarios:

- V2V: DSRC = direct peer-to-peer, C-V2X = direct peer-to-peer
- V2I: DSRC = direct vehicle to roadside unit, C-V2X = direct vehicle to RSU
- V2P: DSRC = direct vehicle to person, C-V2X = direct vehicle to person
- V2N: DSRC = Indirect. Vehicle to roadside unit, using the backhaul network to reach other roadside units. C-V2X = vehicle to mobile network operator using the LTE-Uu interface.

C-V2X essentially replaces the lowest IEEE 802.11p and IEEE1609.4 layers of the communication stack with LTE-based radio technology. A comparison of 802.11p, Release 14, and future Release 16 parameters is shown below.

	802.11p	Release 14/15	Release 16
Synchronization	Asynch	Synch	Synch
Channel Size	10/20 MHz	10/20/Nx20 MHz	10/20/wideband MHz
Resource Multiplexing	TDM	TDM/FDM	TDM/FDM
Data Channel Coding	Convolutional	Turbo	LDPC
HARQ Retransmission	No	Yes	Yes
Waveform	OFDM	SC-FDM	OFDM
Resource Selection	CSMA-CA	Semi-persistent	Several options
MIMO Support	No	2RX, 1TX → 2RX, 2TX	2RX, 2TX → 8RX, 8TX
Modulation Support	Up to 64QAM	Up to 64QAM	Up to 256 QAM

Source: Mobile Experts

Illustration 29. Comparison of Critical DSRC and C-V2X Parameters.

The channel coding and waveforms are credited with extending the range of C-V2X (nearly double) relative to DSRC.

One of the selling points of C-V2X is its ability to work with existing higher-level IEEE, SAE, ETSI, and ISO protocol layers. Proponents suggest existing message sets, network management, and security features can be reused, minimizing incremental investment while enabling a roadmap to future technology. As mentioned earlier, the IEEE 802.11NGV study group is now focused on responding with a roadmap of its own. Note that the upper layers of the protocol stack set the update rate of the application, typically 10 Hz, regardless of how capable the lower radio layers are.

In terms of hardware implementation, C-V2X is currently implemented using a standalone chip available from Qualcomm, much like the DSRC solutions available from multiple vendors. Both are targeting the same spectrum. C-V2X requires two receiving antennas, two RF chains, and a precision timing source; DSRC only requires a single antenna and has a looser timing tolerance. With that said, 802.11NGV is looking to accommodate two antennas in the future and this will neutralize some of the hardware differences.

Will C-V2X ever be integrated into the main modem SoC to eliminate an extra chip? History suggests maybe not. Many of the key players in mobile SoCs optimize around handset designs and then reuse their devices in automotive applications. It can be difficult to rationalize an extra square millimeter or two of die area for purely a limited-volume automotive feature when billions of handsets are produced with those same dies each year. We're simply suggesting economics may have a larger role in C-V2x integration instead of technical merits. In addition, the C-V2X antennas are likely to be located in a different position than the "shark fin" antenna used for LTE connectivity. The priority for C-V2X coverage calls for coverage in the front and rear of the car, and early implementation has been achieved with antennas positioned at either end of the vehicle, instead of the single rooftop location.

Is the path to Release 16 and 5G technologies important to the automotive industry? Autonomous vehicles certainly generate plenty of headlines, but the industry's actions suggest a more conservative position. As we noted in the cellular section earlier, the vast majority of automotive-grade cellular module offerings are LTE Category 4 or 6, with only a few available in Category 9. Modems up to Category 20 are available today for handsets.

Trials of C-V2X technology have started this year in China, Germany, Japan, and the USA (Colorado). Outside early test track situations, transportation departments, auto OEMs, network operators, and infrastructure suppliers are just starting to see how the technology is working in real-world conditions.

In terms of forecasting, like DSRC we have to consider government, infrastructure, and auto OEM commitments.

- China is the only country with spectrum specifically earmarked for C-V2X at this time (5905 – 5925 MHz). The other main market regions originally allocated spectrum for DSRC. China is not mandating V2X deployment at this time, and they are loosely tying this technology to their intelligent and connected vehicle initiatives (autonomous vehicles).
- We suspect RSU deployments for C-V2X may be delayed in time relative to DSRC-based RSUs. It's not the cost of the RSUs themselves that is the issue; it's the cost of each site. RSUs typically cost a few thousand dollars each, but installing poles, electricity, and backhaul can cost tens of thousands of dollars. There may not be enough budget for running two pilots concurrently in separate locations, and the two pilots can't share the same location as they use the same spectrum and will likely interfere with each other. Therefore, if the budgets truly are constrained then we expect big pilot projects to go a period of time on one technology and a period of time on the other technology to collect data and compare results.
- No auto OEMs have announced plans to go to production with C-V2X technology yet.

With automotive design cycles typically taking 3-4 years for refreshes and 7-8 years for major platform changes, we may not see C-V2X mass production announcements until the end of our forecast period--assuming the major economic regions adjust their spectrum assignments, the local transportation authorities refresh their infrastructure plans, and financial models and budgets are reconsidered. Without government mandates for a V2X safety technology and with the competition between two technologies, we expect changes to happen slowly. At this point we only expect vehicles destined for the Chinese market to utilize C-V2X, and only when their NCAP roadmap shows V2X on it. We believe the earliest we'll see C-V2X shipments in volume will be the mid- to late-2020s, at which point it will achieve mature volume shipments as vehicle powertrain, braking, and suspension platforms are updated to take advantage of this new input.

In the North American market, adoption of Cellular V2X depends on the policy of the US Government. If the USA mandates the use of DSRC for V2X communications, then the world will be split. But if the USA shifts to cellular, or applies no mandate at all, then we expect C-V2X to become more standard over time worldwide.

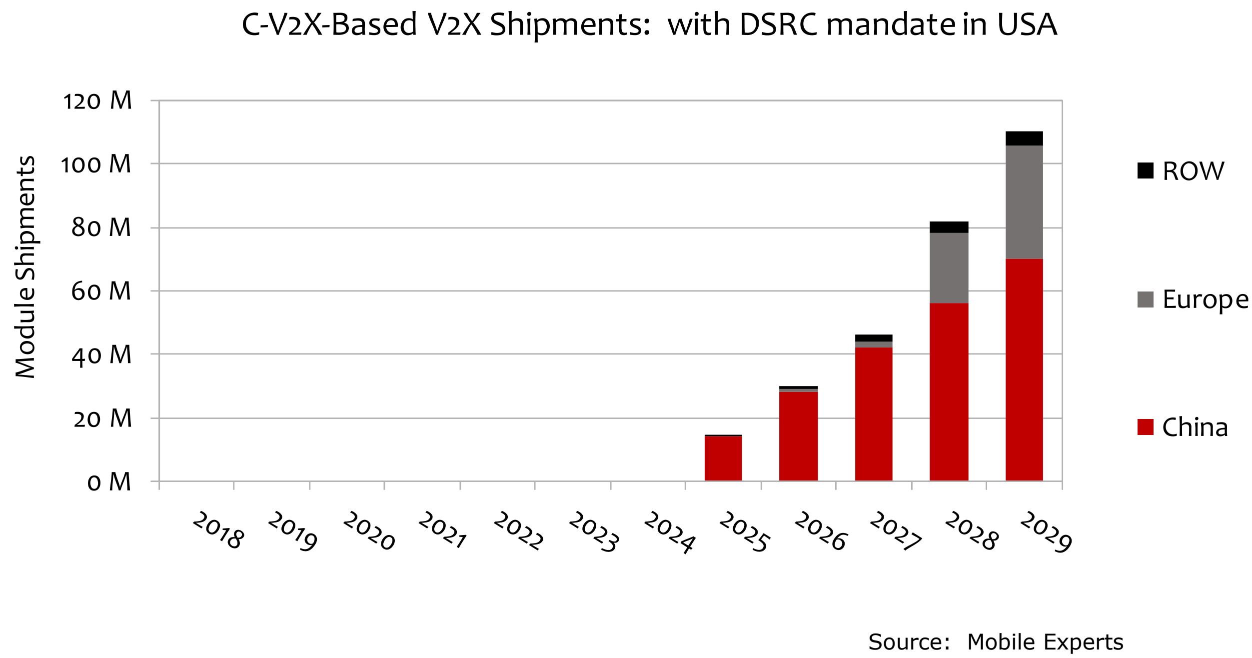


Chart 15. Projected C-V2X module shipments, with DSRC mandate

* Assumptions: OEMs start next-gen platform updates integrating C-V2X with powertrain, braking, and suspension systems in 2019, and bring vehicle models based on the new platform to market starting in 2025. We assume that China would mandate C-V2X for all cars in the 2029 timeframe.

Under the scenario where the US Government does not mandate C-V2X, then we anticipate a shift in Japan and Europe to embrace C-V2X. In this case, the US market is likely to be idle, so the additional shipments are not as big as they could be otherwise.

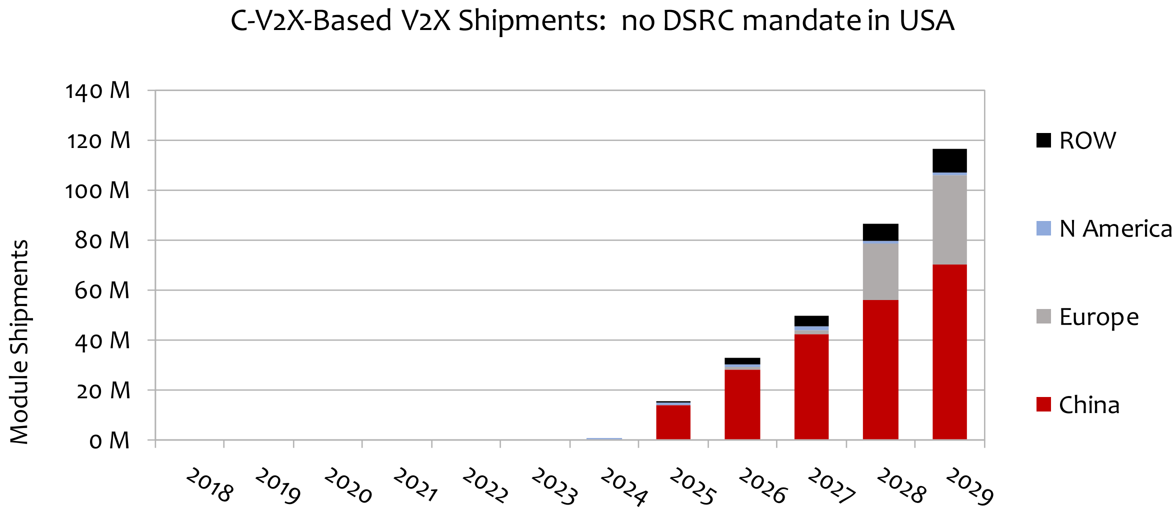
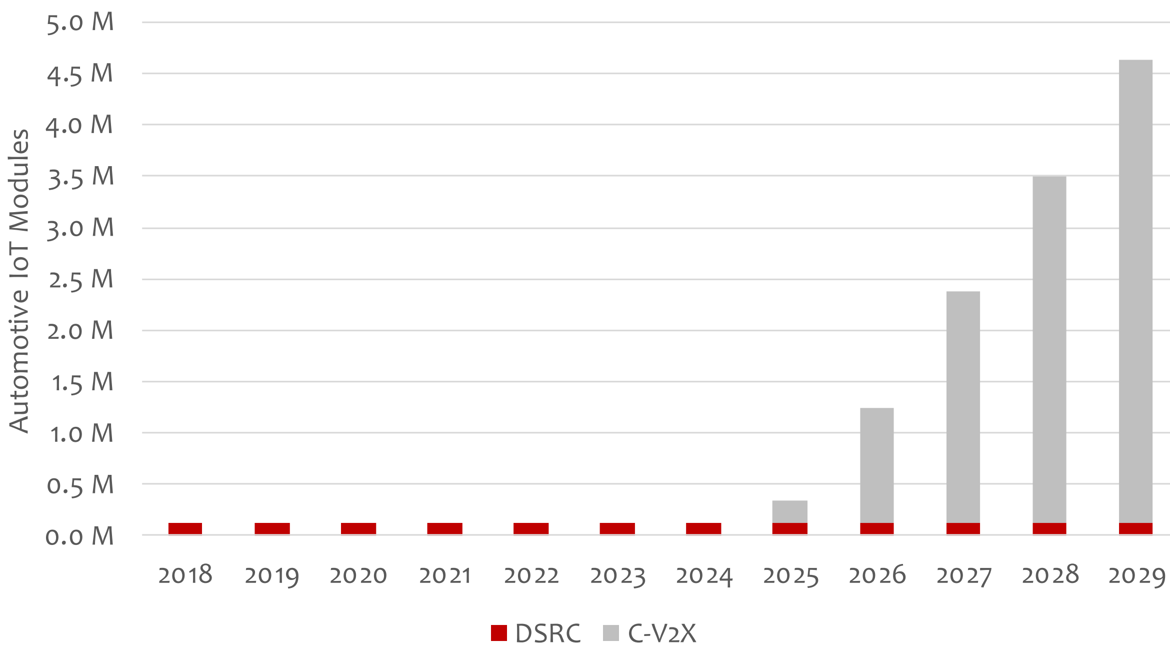


Chart 16. Projected C-V2X module shipments, no DSRC mandate

* Assumptions: OEMs start next-gen platform updates integrating C-V2X with powertrain, braking, and suspension systems in 2019, and bring vehicle models based on the new platform to market starting in 2025. We assume that Europe and China would mandate C-V2X for all cars in the 2029 timeframe.

Overall, we see a shift away from DSRC in favor of C-V2X. Despite the preferences of the engineers at Toyota, GM, Honda, and other auto manufacturers, after another 4-5 years the overall market will see C-V2X as a more current technology, and 802.11p will be viewed as "old" technology. The most likely case is that the Chinese market will move more quickly than other regions, setting a new standard.



Source: Mobile Experts

Chart 17. Overall forecast for V2X modules

6: ACRONYMS

2G	Second-generation cellular technology
3G	Third-generation cellular technology
3GPP	Third Generation Partnership Project
4G	Fourth-generation cellular technology
5G	Fifth-generation cellular technology
ABS	Anti-lock Brake System
ADAS	Advanced Driver Assistance Systems
ANPR	Automatic Number Plate Reader
ARIB	Association of Radio Industries and Businesses
AVL	Automatic Vehicle Location
BHPH	Buy Here Pay Here
BPSK	Binary Phase Shift Keying
CP	Cyclic Prefix
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
C-V2X	Cellular Vehicle-to-Everything
D2D	Device to Device
DCC	Decentralized Congestion Control
DIS	Draft International Standard
DMS	Dealership Management System
DMV	Department of Motor Vehicles
DSRC	Dedicated Short Range Communications
EDGE	Enhanced Data GSM Environment
ELD	Electronic Logging Device
EN	European Norm
ETC	Electronic Toll Collection
EU	European Union
EV	Electric Vehicle
EWD	Electronic Work Diary
FCC	Federal Communications Commission
FDIS	Final Draft International Standard
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
FMCSA	Federal Motor Carrier Safety Administration
GDP	Gross Domestic Product
GFSK	Gaussian Frequency Shift Keying
GHz	Gigahertz
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global System for Mobile communications
HOS	Hours Of Service

HOV	High Occupancy Vehicle
HVAC	Heating, Ventilation, Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IoT	Internet of Things
ISM	Industrial Scientific Medical
ISO	International Standards Organization
ITS	Intelligent Transportation Systems
ITS-G5	Intelligent Transportation Systems-5 Gigahertz
IVI	In-Vehicle Infotainment
LCD	Liquid Crystal Display
LDPC	Low Density Parity Check
LTE	Long-Term Evolution
M2M	Machine to Machine
MAC	Media Access Control
MEMA	Motor Equipment Manufacturers Association
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MRM	Mobile Resource Management
NCAP	New Car Assessment Program
NOCoE	National Operations Center of Excellence
NR	New Radio
OBD-II	On Board Diagnostics II
OBU	On Board Unit
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplexing
OTA	Over The Air
PAN	Personal Area Network
PAYD	Pay As You Drive
PC	Personal Computer
PHY	Physical layer
PHYD	Pay How You Drive
PPS	Pulse Per Second
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radiofrequency
RFID	Radiofrequency Identification
RSU	Roadside Unit
RX	Receiver
SAE	Society of Automotive Engineers
SC-FDM	Single Carrier Frequency Division Multiplexing
SPaT	Signal Phase and Timing
TDM	Time Division Multiplexing
TS	Technical Specification

TX	Transmitter
UBI	Usage-Based Insurance
UHF	Ultra-High Frequency
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WAVE	Wireless Access in Vehicular Environments
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network

7: METHODOLOGY

Mobile Experts interviewed 25 companies across the automotive ecosystem including semiconductor suppliers, module suppliers, Tier-1 suppliers, aftermarket telematics suppliers, mobile network operators, road infrastructure/mobility system providers, insurance companies, and a US-based state DOT.

Additionally, we reviewed annual reports and press releases from OEMs and dealership networks, industry statistics from specific verticals such as rental car fleets and electronic tolling systems, and revenue/profitability data for music streaming services. Furthermore, we investigated government mandates for vehicle safety as well as regulatory assignments of spectrum.

After building as much of a top-down picture as possible, we also used existing shipment information and trends to build a bottom-up picture and merge the two together.

8: EXTERNAL CHART AND ILLUSTRATION SOURCES

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Chart 4: Cumulative Sales of Plug-In Electric Vehicles
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Illustration 6: Using RFID to Scan a Prototype Vehicle
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Illustration 7: A Typical Assembly Line Station
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Illustration 19: Active RFID Transponder

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